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# HOLOCENE OSTRACODS, OTHER INVERTEBRATES AND FISH REMAINS FROM CORES OF FOUR MAAR LAKES IN SOUTHEASTERN AUSTRALIA

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Abstract: Cores from 4 maar lakes in Western Victoria yielded ostracods (most abundant), foraminifers, gastropods, cladocerans, isopods, sponges, chironomids, trichopterans, and some fish remains; these faunas are described herein. From the present day ecology of most of these organisms, especially the ostracods, changes in lake levels and salinities are inferred. During the last 9 000 years, fluctuation in water level and consequently salinity is nearly always synchronous in 3 of the lakes: Bullenmerri (salinity today 4.5-8.5°/₀₀), Gnotuk (today 55-63°/₀₀) and Keilambete (today 55-62°/₀₀). Lake Purrumbete (salinity ~0.4°/₀₀ today) has remained fresh during the last 7 000 years probably resulting from continuous connection to a river.

The following events are inferred as having occurred synchronously in the 3 Lakes Bullenmerri, Gnotuk and Keilambete and are thought to result from climatic changes since these lakes are small, enclosed basins. 1, during the last 100 years, lake levels have fallen significantly; 2, during the 2 000-3 000 yBP period lake levels were low; 3, between 3 800 and 6 400-6 500 yBP water levels were high and the highest lake levels occurred between 5 700 and approximately 6 400 yBP; 4, before 8 300 yBP water levels were at their lowest (i.e. highest salinities) in Lakes Keilambete and Gnotuk (no record for Lake Bullenmerri) for the Holocene.

Core from Lakes Bullenmerri, Gnotuk, Keilambete and Purrumbete exhibit changes in the fossil lacustrine fauna. These changes are attributed to changes of lake salinity which in turn are attributed to variation in water levels in the lakes; the water levels indicate fluctuations in climate during the past 10 000 years. The lakes cover a broad spectrum of salinities (see Table 1) and correspondingly have different faunas. Thus the recovery of different ostracods (the commonest fossil invertebrates) from the cores, and knowledge of salinity tolerance of the species today provide palaeosalinity data. With information on the present hydrology of each lake, a correlation of the salinity curve with that of a climatic one may be attempted as radiocarbon dates (Barton & Polach 1980, Bowler & Hamada 1971, Dodson 1974), are available for correlation between the cores.

Lakes Bullenmerri, Gnotuk, Keilambete and Purrumbete are located near Camperdown, approximately 170 km west southwest of Melbourne and about 30 km from the sea (Fig. 1). They are situated within the Western Victorian Newer Volcanic Province which is of Pliocene to Recent age (Ollier & Joyce 1964) and overlies Miocene limestone (Joyce 1975).

Each lake occurs inside a shallow volcanic crater described as a maar. According to Ollier (1968), a maar is a landform caused by volcanic explosion consisting of a crater which reaches or extends below, general ground level; it is considerably wider than it is deep and has a surrounding rim constructed of material ejected from the crater.

Physical data on the four lakes are provided in Table 1. Lakes Bullenmerri and Gnotuk are adjacent craters formed by distinct volcanic explosions (Ollier 1970) and only once in human memory is Lake Bullenmerri known to have overflowed into Lake Gnotuk (Currey 1970). Lake Bullenmerri is clover-leaf shaped, and has steep sides (Fig. 2). Present water level is 21 m below the point of overflow into Lake Gnotuk.

Lake Gnotuk is much smaller, oval shaped, and flat-bottomed (Fig. 2). The water level is about 40 m below that of Lake Bullenmerri. Circular Lake Keilambete is flat-bottomed. Salinity varied between 55.3 and 62.4°/₀₀ in the last 15 years (Maddocks 1967, Hussainy 1969a, Bowler 1970).

Lake Purrumbete has steep flanks with a gentle slope towards its centre (Fig. 2).

Lakes Bullenmerri, Gnotuk and Keilambete are internal drainage basins: water in the lakes results from precipitation and crater slope run-off and in each case there does not seem to be much interference with groundwater (Bowler 1970, Currey 1970). An exception occurs when Lake Bullenmerri overflows into Lake Gnotuk. Lake Purrumbete can also overflow into Curdies River which is at about the same altitude as the lake at its present level. Water chemistry of the four lakes has been studied by Maddocks (1967). The fauna of Lakes Bullenmerri, Gnotuk and Purrumbete was studied during the 1969-72 period (Timms 1973, 1980, 1981) and the 1967-68 period (Hussainy 1969a). The flora of the four maars was examined by Yezdani (1970) and Tudor (1973). The latter concentrated on the diatoms.

Palaeolimnological work has already been carried out on these four maar lakes. Yezdani (1970) described changes in the aquatic flora (using pollen and diatoms) of Lakes Gnotuk and Bullenmerri. Tudor (1973), using diatoms only, described changes in water quality for some periods of the history of Lakes Keilambete and Gnotuk. Bowler (1970, 1981) examined the sediments in cores from Lake Keilambete and its margins; he established a water level curve for the last 30 000 years

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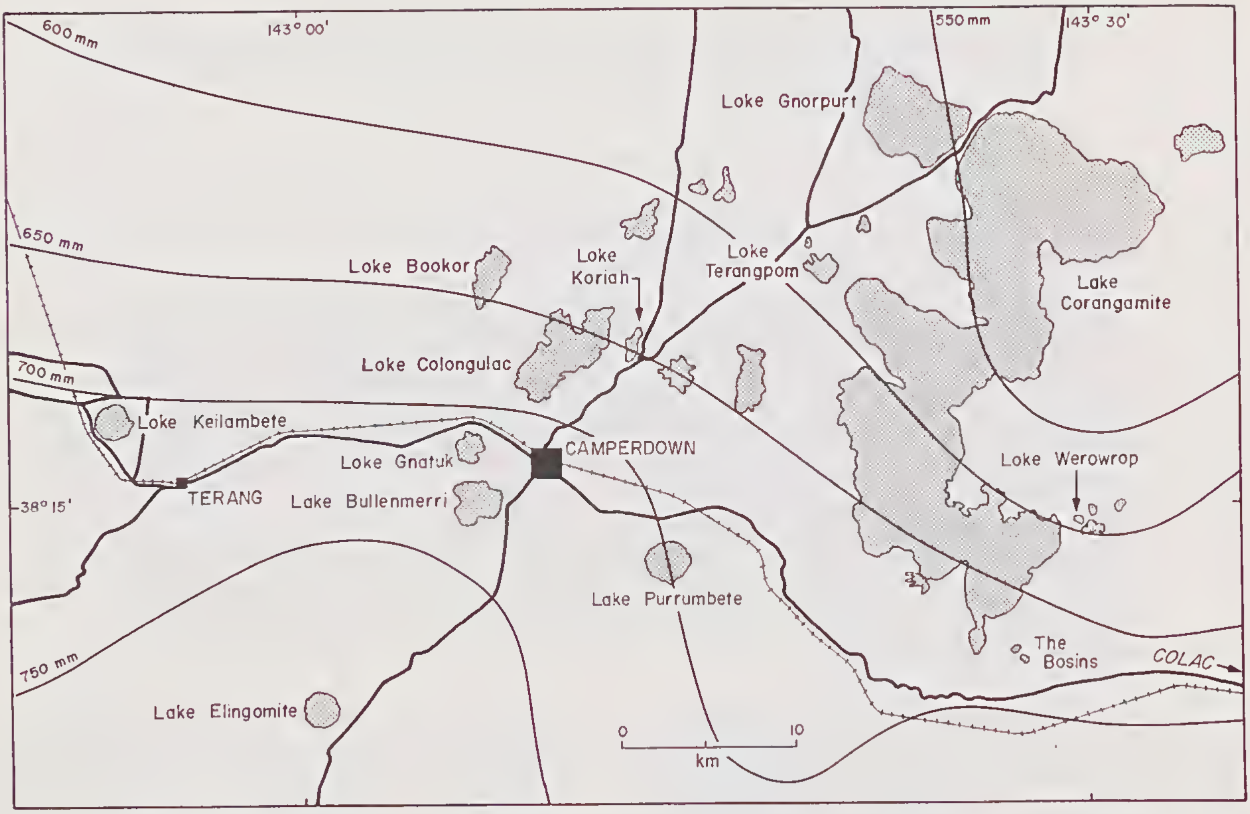


FIG. 1—Map showing the location of the four maar lakes in Victoria; Camperdown is situated 190 km west of Melbourne.

(Bowler & Hamada 1971, Bowler 1981). Dodson (1974) presented a palynological curve for the same lake for the last 10 000 years. His data reveal changes in vegetation surrounding the lake, accompanied at times, by modifications in the aquatic vegetation because of changes in water salinity. Churchill *et al.* (1978) published a water level curve derived from salinities indicated by diatom communities for Lakes Bullenmerri and Gnotuk extending back to 5 500 and 7 500 years respectively. Barton (1978), Barton & Polach (1980) and Barton & McElhinny (1981) have collated a 10 000 year geomagnetic secular variation record from many cores of Lakes Bullenmerri, Gnotuk and Keilambete. Finally, Dodson (1979) presented a pollen record from a core taken from the deepest part of Lake Bullenmerri and covering the 8 000 to 16 000 yBP period.

## METHODS

A 6 m long pneumatic corer, similar to that designed by Mackereth (1958) fitted with an orientating device (Barton & Burden 1979) was used to core each lake. The 54 mm diameter cores were originally taken for palaeomagnetic investigation of the sediments (Barton 1978). Cores were cut into 1 to 2 m sections to facilitate transport. Rubber bungs inserted at the ends of most sections compressed sediment by about 2 cm. The cores were later split open lengthwise and sedimentological decription was completed, often under a binocular microscope. Sampling was carried out by extracting 3 g of sediments each time. The numbers of each sample for all cores refer to their appropriate levels in cm below the top of the core. Each sample was kept in a sealed 200 ml jar in a 10% hydrogen peroxide solution for one to two weeks depending on the separation rate of clays and dissolution of organic matter. The contents of the jar were then gently washed with a water jet over a 200 μm sieve (a finer sieve would have retained valves of unidentifiable juvenile ostracods). The residue was dried in a low temperature oven and picked under a binocular

TABLE 1
MORPHOMETRIC AND SALINITY DATA ON THE FOUR MAARS

| | Bullenmerri | Gnotuk | Keilambete | Purrumbete |
|---|---|---|---|---|
| Surface area (ha) | 448[1] | 208[1] | 277[2] | 522[1] |
| Volume ($10^6$ $m^3$) | 192[1] | 32[1] | 13.3[3] | 157[1] |
| Maximum depth (m) | 66[1], 67[6] | 18.5[1], 20[6] | 11[2], 10[6] | 45[1], 42[5] |
| Mean depth (m) | 39.3[1] | 15.3[1] | 9.54 | 28.5[1] |
| Salinity (TDS °/oo) 1979-80 | 4.49-8.57 | 55-63 | 62.4 (Jan. 1980) | 0.37-0.44 |
| Other periods | 7.8-8.5[1] | 56-62[1] | 55.3[4], 61.3[6] | 0.42-0.50[1] |

[1] Timms, 1976; [2] Bowler, 1970; [3] calculated from Bowler, 1970; [4] Maddocks, 1967; [5] Barton, 1978; [6] Hussainy, 1969a.

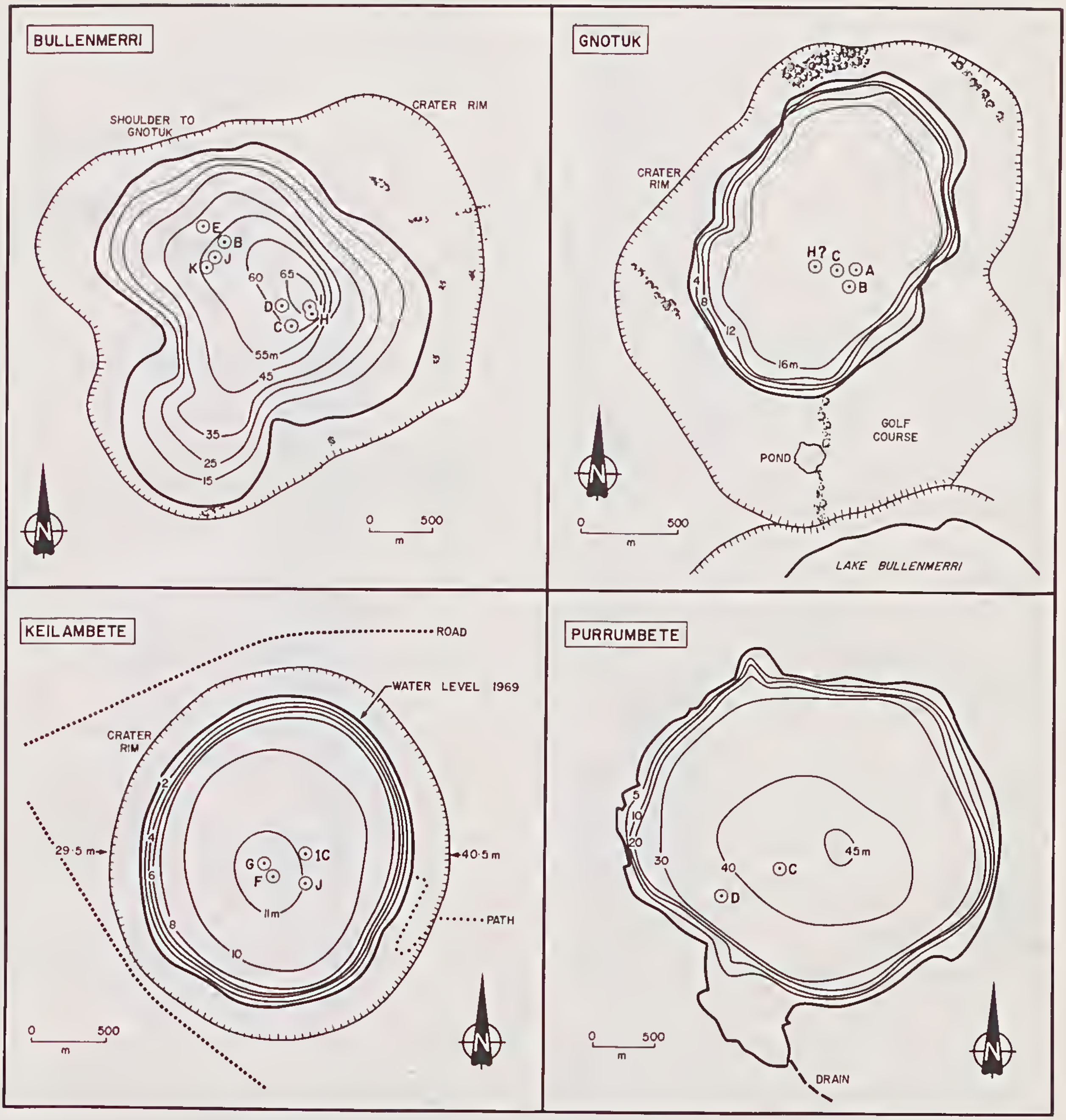


Fig. 2—Bathymetry and location of core sites for each of the four maar lakes.

microscope. Every ostracod was examined and counted. When specimens were particularly numerous (>1 500 individuals), an estimate of their number was made. The presence of other fossil remains was also noted. Conventional $^{14}C$ dates are used throughout this paper.

## DESCRIPTION OF THE CORES

### Lake Bullenmerri

A core 533.5 cm long was taken on 1 March, 1977 at a depth of 55.5 m in the northwestern part of the lake (Fig. 2, location K). The coring site could differ from this location by about 100 m (C. E. Barton pers. comm.). The core is labelled BK. Details of the core are given in Fig. 6. The core consists mainly of fairly homogeneous organic mud. Two colorations occur:

a, brown to dark brown to grey brown organic mud with abundant fine (100-200 μm thick) or occasionally coarse (ca. 1 mm) laminations. The fine laminations are usually black whereas some of the coarse ones vary from beige brown to orange brown to white in colour;

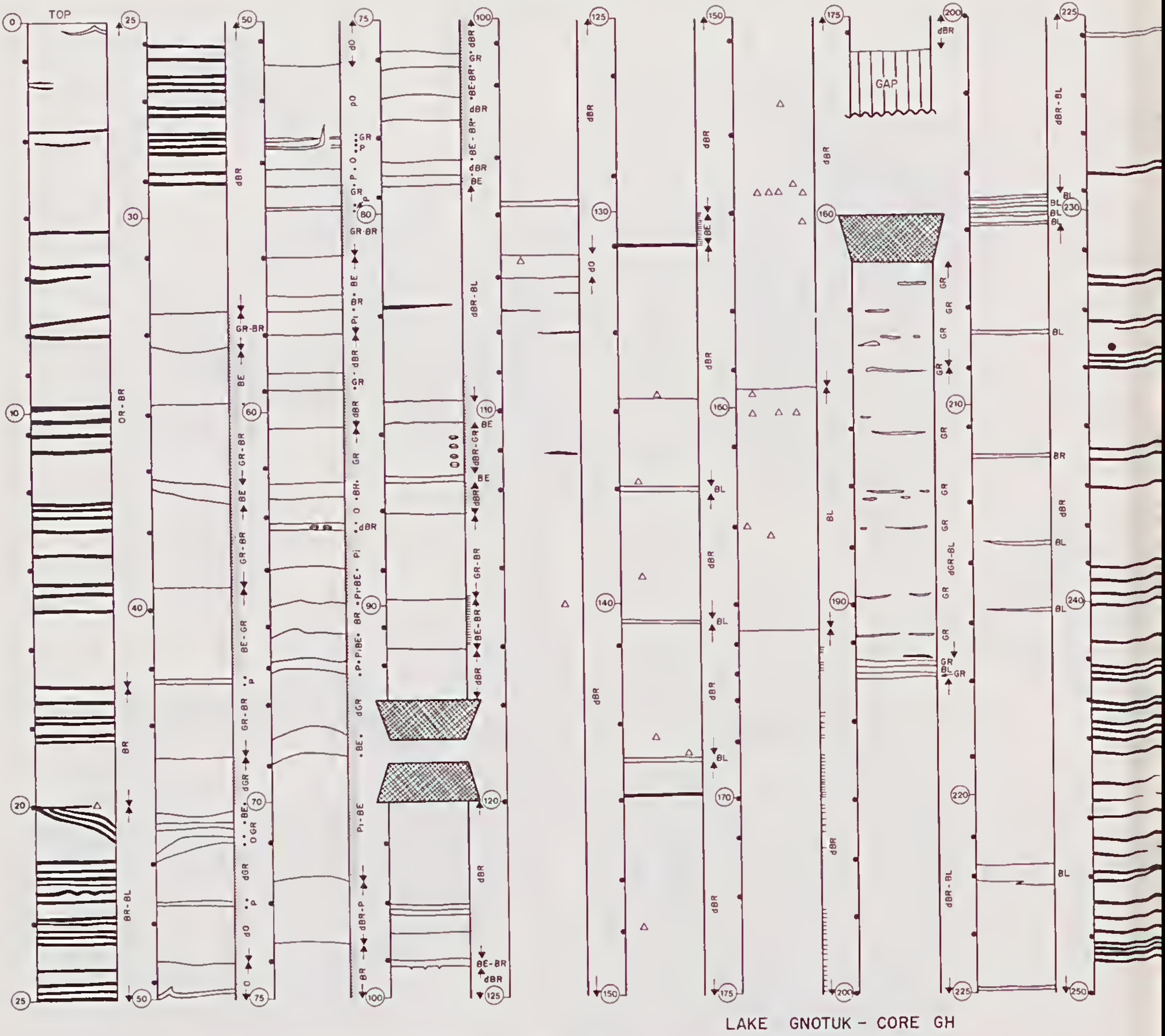


FIG. 3 — Detailed lithological description of core GH from Lake Gontuk. For legend see Fig. 4. Black dots indicate the position of the samples in the core.

- b, dark grey to black unlaminated organic mud below level 400 cm.

After treatment of some of the samples with $H_2O_2$, small grains (>200 $\mu$m) consisting mainly of scoria fragments were found. Their presence in the core is referred to in Fig. 9 and their significance will be discussed later. The "sulfureous orange muds" described by Barton (1978) at the bottom of his much longer cores (ca. 10 m long) are not encountered in core BK.

### LAKE GNOTUK

A core 362.5 cm long was taken on 7 March, 1977 at a water depth of 19 m near the centre of the lake. Its exact location is queried by Barton (1978). The core is labelled GH. Details of the core are given in Fig. 3.

A variety of sediment types was encountered and these are described in descending order:

- brown to dark brown organic mud with numerous white to beige carbonate bands (ca. 1 mm) down to 32 cm. A small hiatus with contorted bedding was noticeable at level 21 cm.
- dark brown to black organic mud alternating with light and dark thick layers (ca. 1 cm) with many ostracod shells (*Diacypris compacta*) down to 88 cm. The shells are sometimes so abundant that the layers have a sandy appearance.
- brown to dark brown to black organic mud with some pale brown to olive green layers and many very fine black laminations (ca. 100 $\mu$m) down to 175 cm.

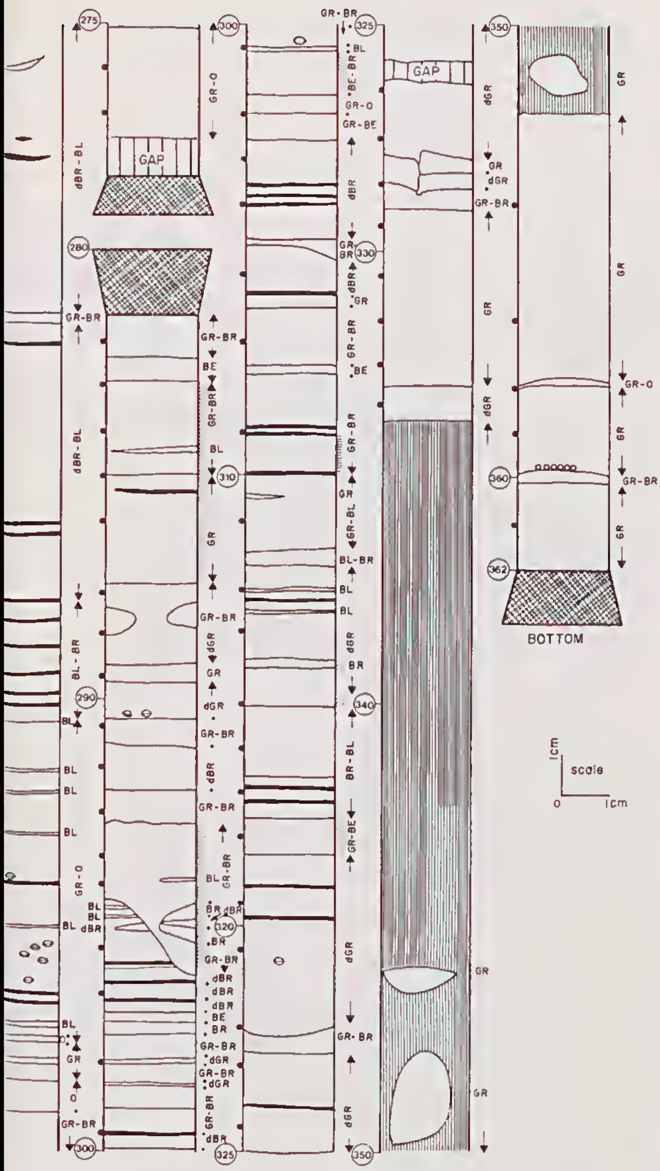


FIG. 3—(*continued*).

The average distance between these thin black laminations ranged between 450 $\mu$m and 600 $\mu$m.

- dark brown to black organic mud with thin (<1 mm) grey or black or brown layers at irregular intervals down to 231 cm.
- between 231 cm and 266 cm, dark brown to black organic mud with abundant white to grey layers, especially between level 231 and 250 cm (large crystals of aragonite occur in some of these light coloured layers)
- grey-green organic mud down to 285 cm grading into grey to dark grey organic mud down to 325 cm. Pale coloured thin bands more common in the upper part. A small truncation of bedding was noticeable around level 295 cm.
- grey to dark grey organic mud down to 333.5 cm. No sediments recovered between that layer and level 346 cm.
- grey clay from 346 cm to 362 cm. The upper 6 cm appear to have been mixed. This entire layer is probably displaced as suggested by the gap above it.

### LAKE KEILAMBETE

Two cores were taken: a short one, 127 cm long and labelled K1C was collected on 5 December, 1976, slightly east of centre of the lake where it is about 10 m deep. This core was taken to obtain the uppermost layers of sediments not recovered in the longer core. The latter, labelled KG and collected on 29 April, 1975, is 419 cm long and was taken at the centre of the lake at a depth of 10.5 m. For location of both cores, see Fig. 2, and their lithological description, see Figs 4, 5. The top of core KG is at about 40 cm below the water sediment interface (see correlation between the two cores—Table 3 and Figs 4, 5, 8 and 9). Forty-nine samples were examined from core KIC and 172 from core KG. Bowler (1970, 1981) provided a detailed stratigraphic log of a 440 cm long core (labelled K4) from Lake Keilambete. This will not be repeated here as the core was taken from another part of the lake with distinct facies differences. Notably, the grey mud recovered at the bottom of core KG (Fig. 5) was not found by Bowler in core K4. Additionally, the sandy layers mentioned by Bowler (*op. cit.*) in his cores K4 and K5 are not found in core KG. The broad sedimentary divisions given by Bowler (1981) are used here:

- top of core to 200 cm (core K4) = *Upper Keilambete Muds* consisting of fine grained dark calcareous muds with paler carbonate rich bands and occasional sandy horizons (150 cm, 100 cm). This unit apparently terminates at level 153 cm in core KG and comprises the whole of core K1C.
- 200 cm to 375 cm (core K4) = *Lower Keilambete Muds* consisting of fine grained dark muds which are weakly calcareous. The basal part of this unit cannot be defined in core KG as the other two units described by Bowler (1981) as the *basal saline sands* (zone 375-440 cm) and the basal soil (400-440 cm) are missing in core KG. It is thought that the *basal soil* probably is facies equivalent to the grey to brown mud found in core KG below level 350.5 cm and finally grading into the grey mud below level 385.5 cm.

Throughout the entire core, there are many bands, sometimes more than 1 cm thick, which consist mainly of ostracod shells (Fig. 4). Below levels 355 cm and 387 cm in core KG, bedding is disturbed: these are probable signs of aerial exposure of the lake floor.

### LAKE PURRUMBETE

A 581 cm long core, labelled PC, was taken on 2 June, 1975, at a depth of 40.8 cm near the centre of the lake (Fig. 2). Note the bathymetric map provided by Barton (1978) differs from Timms' map (1976). The core is entirely homogeneous dark brown organic mud. Small gas vesicles are common in the more fluid upper 113 cm of the core; below that level, the organic mud becomes

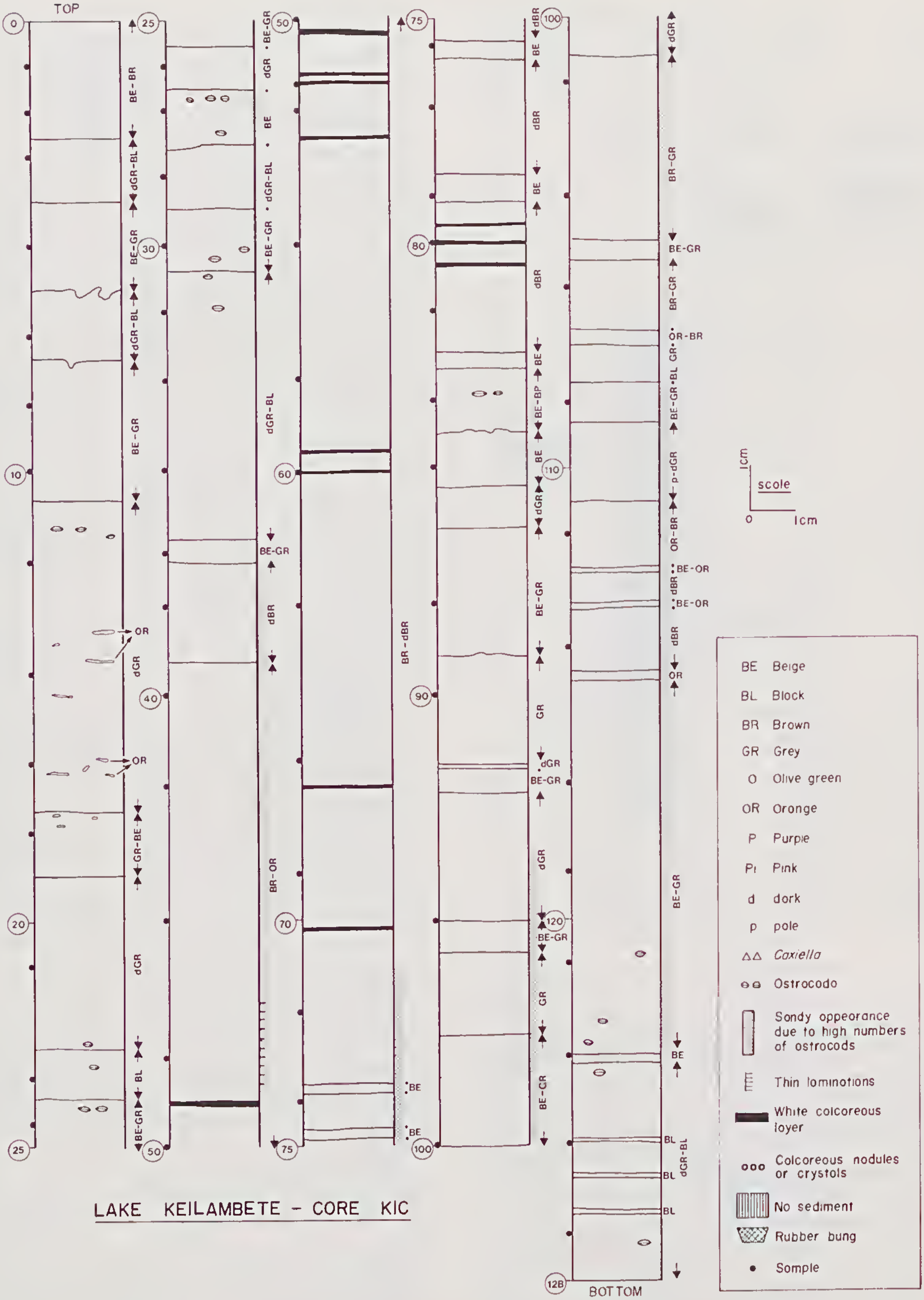


FIG. 4—Detailed lithological description of core KIC from Lake Keilambete.

more compact with increasing depth. 195 samples, usually taken at 3 cm intervals were analyzed from core PC (Fig. 10).

## SYSTEMATICS

Distribution of fossils in the cores is given in Figs 6-10.

### OSTRACODA

Ostracods, which have a calcareous shell, are readily preserved in lake sediments. Their fossils are informative on the environmental conditions in the lakes at the time these ostracods lived. The study of fossil ostracods from Australian salt lakes is of importance since the halobiont ostracod fauna is unusually diverse (De Deckker 1981d) as many species have distinct ranges of salinity tolerance. In addition, as the ostracod fauna in salt lakes is represented mostly by planktonic species, shells of the same species should be fairly evenly distributed on lake floors. This should permit easy correlation between cores taken from any part of a lake.

**Australocypris robusta** De Deckker 1974
Fig. 13M-Y

1974 *Australocypris robusta* De Deckker, p. 65.

DESCRIPTION: Adult: valves large (ca. 3 mm), oblong, extremely thin, and smooth to pseudopunctate; greatest height at about 0.4 from anterior which is broadly rounded compared to the narrower posterior; ventral margin almost straight except for the slightly concave mouth region; inner margin narrow anteriorly and posteriorly. Juvenile: valves subtriangular to almost round; greatest height between 0.3 and 0.5 from anterior.

ECOLOGY: *A. robusta* is a good swimmer but is also found on lake floors. Its salinity range in Victoria is 7-145°/∘∘ (De Deckker 1981a) but in South Australia, in lakes near the Coorong Lagoon, it is 15-38°/∘∘ (De Deckker & Geddes 1980). The broader salinity range of the Victoria specimens probably relates to the fact there is no other *Australocypris* species in salt lakes in that area (i.e. interspecific competition is lacking) whereas in the lakes near the Coorong Lagoon, 3 additional species (*A. insularis* (Chapman 1966), *A. rectangularis* De Deckker 1978 and *A. dispar* De Deckker 1981) probably have to compete for similar niches. The salinity range of the present day Victorian specimens is attributed to the fossil material as, so far, no fossil remains of *A. insularis* have yet been found in Victorian lacustrine sediments. In Victorian lakes, *A. robusta* is encountered in high numbers between 45 and 77.5°/∘∘ salinities and nearly always it co-occurs with large numbers of *D. compacta*. At higher salinities, these 2 species are found with *P. baueri*.

REMARKS: *A. robusta* specimens are rarely found intact, especially at the adult stage, because they are very brittle—fracture of the shell often results from slight compaction even during a very careful extraction of a sample from a core. Juveniles of *A. robusta* are distinguished from both *Diacypris* species by: the greatest height of *A. robusta* being very close to the anterior margin (ca. 1/4), its shell more rounded and its valves much broader in dorsal view. No carapaces of *A. robusta* were ever found nor large quantities of large specimens typical of layers occasionally found on the shore of lakes which dry up. This suggests that the edge of the lake, where such a phenomenon would occur, has never been near the coring sites (in Lakes Gnotuk and Keilambete).

**Candonocypris novaezelandiae** (Baird 1843)
Fig. 12W

DESCRIPTION AND SYNONYMY: See De Deckker (1981b).

ECOLOGY: This freshwater species is common in farm dams and eutrophic waterbodies. For more details see De Deckker (1981b). *C. novaezelandiae* lives today in Lake Purrumbete (Hussainy 1969, Timms 1981, called by them *C.assimilis*) down to 33 m (Timms 1973).

REMARKS: Very few specimens were found in the cores. The adult shells were either partly decalcified or partly perforated. This was probably caused by waters of low pH. This phenomenon can be expected as *C. novaezelandiae* is often crawling in among decaying vegetal debris.

**Diacypris compacta** (Herbst 1958)
Fig. 15A-P

1958 *Pseudocypris compacta* Herbst, p. 181.
1960 *Diacypris compacta*; Herbst, p. 143.
1981e *Diacypris occidentalis* McKenzie; De Deckker p. 54.
1981e *Diacypris paracompacta* McKenzie; De Deckker, p. 54.
1981e *Diacypris parva* Hartmann; De Deckker, p. 54.

DESCRIPTION: Adult: valves pesudopunctate, almost circular in shape and narrow in dorsal view; greatest height at about 0.3 to 0.5 from anterior margin; posterior area broadly rounded. Inner lamellae broader anteriorly. Left valve overlaps right one all along its periphery but overlap is more obvious in dorsal area where a hump is present in left valve only. This hump is variable; occasionally it is pointed. Juvenile: valves more triangular in lateral view and dorsal hump usually absent.

ECOLOGY: This is an ubiquitous halobiont species; its salinity range is very broad and it is an excellent swimmer. It occurs in large numbers over its entire salinity range. In the lakes near the Coorong Lagoon in South Australia, its range is 8-132°/∘∘ (De Deckker & Geddes 1980) and in western Victorian lakes it is 14-181°/∘∘ (one specimen was even collected at 0.34°/∘∘). In West Australian lakes, it has been collected in ten lakes in the range of 2.9-87.9°/∘∘ (Geddes *et al.* 1981).

As for *A. robusta*, the salinity range of *D. compacta* in Victoria appears to be wider; this probably results from the absence there of the *Diacypris* species which have a higher salinity tolerance as those from the lakes near the Coorong Lagoon, e.g. *D. dictyote, D. fodiens* and *D. whitei*. *D. compacta* has been found on many occasions in extremely large numbers (e.g. ca. 20-40 ml of settled ostracods filtered from 1 m of lake water) resulting from "blooms" of that species. This phenomenon usually occurred at salinities around 45-77°/∘∘

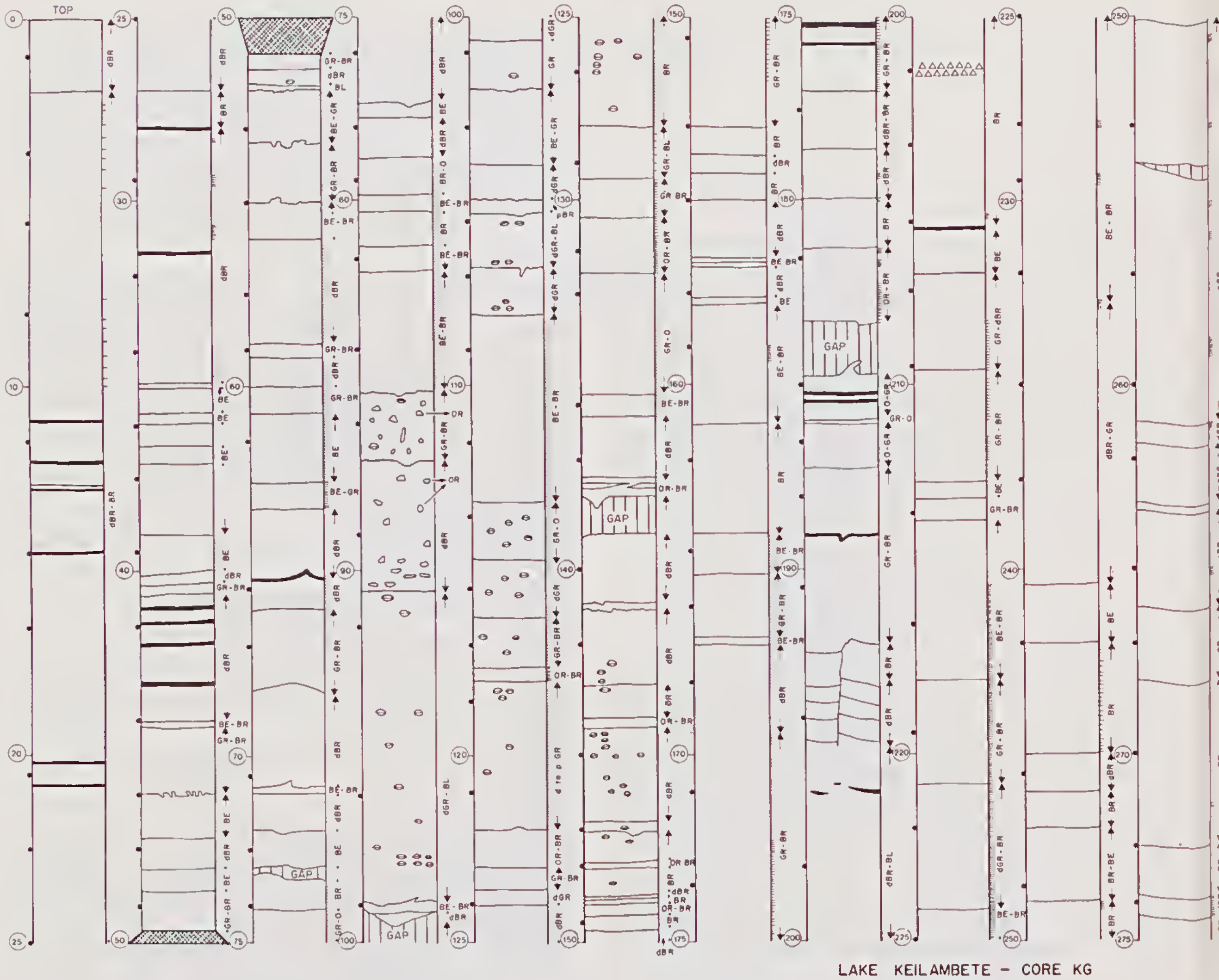


Fig. 5—Detailed lithological description of core KG from Lake Keilambete. For legend see Fig. 4.

in Victorian lakes and in lakes near the Coorong Lagoon. In the cores from Lakes Gnotuk and Keilambete, there are layers (up to 2 cm thick) which have a sandy texture and which consist mainly of *D. compacta* shells. This feature is thought to derive from such "blooms". Once *D. compacta* was found in large numbers at 124°/oo in Pink Lake in western Victoria; in the Coorong area, the "bloom" condition extends down to lower salinities: 21-69°/oo with also two high records at 96 and 123°/oo (see De Deckker & Geddes 1980).

It is not known whether the wide variations of the dorsum of *D. compacta*, which is a diagnostic feature for the species, is of any ecological significance.

**Diacypris dictyote** De Deckker 1981
Fig. 14EE-II, KK
1980 *Diacypris* n.sp.1 De Deckker & Geddes, p. 692.
1981 *Diacypris dictyote* De Deckker, p. 49

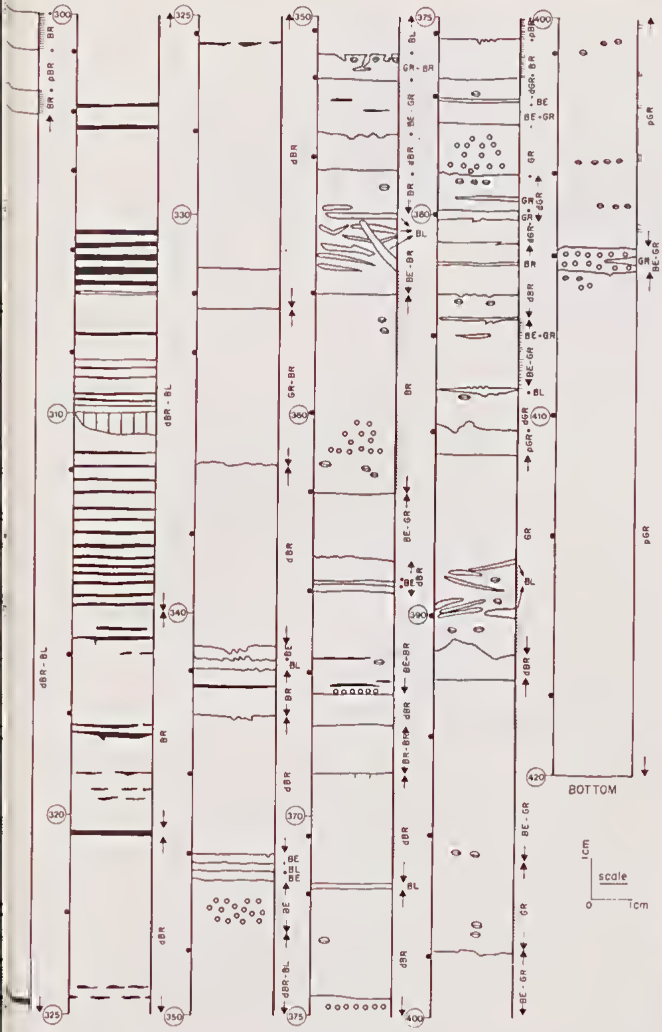
Description: see De Deckker (1981e).

Ecology: So far this species has only been found living in South Australia, in many ephemeral lakes near the Coorong Lagoon, (De Deckker & Geddes 1980), some on Kangaroo Island and on the Yorke Peninsula. In the Coorong area, the salinity range of this species over a year was 12-143°/oo with one record at 195°/oo.

Remarks: *D. compacta*, which also has a sharp dorsal "keel" is easily distinguished from this species by its smooth and smaller shell, the absence of spines and its narrow shape in dorsal view.

**Diacypris dietzi** (Herbst 1958)
Fig. 14U-Z, AA, JJ
1958 *Pseudocypris dietzi* Herbst, p. 177.
1960 *Diacypris dietzi*; Herbst, p. 143.

Description: Triangular shell in lateral view with greatest height at about middle; dorsum steeply inclined and straight behind the highest point of the shell; no strong overlap of left valve over right one in dorsal area; valves narrow in dorsal view.



**Ecology:** This species is not common in salt lakes: in a survey of 79 lakes in western Victoria it was collected only six times whereas *D. compacta* was collected twenty times and *Australocypris robusta* nineteen times. In the Victorian lakes, its salinity range was 35-127°/∞ with one specimen collected at 0.34°/∞. In the lakes near the Coorong Lagoon, its salinity range is broader: 4-141°/∞ with a few specimens found once at 216°/∞ (De Deckker & Geddes 1980). Presence of valves of fossil *D. dietzi* in low numbers in the cores cannot suggest more than a broad range of salinity.

**Diacypris whitei** (Herbst 1958)
Fig. 14BB-DD.

1958 *Pseudocypris whitei* Herbst, p. 185.
1968 *Diacypris whitei*; Herbst, p. 143.

**Description:** Smooth, rectangular shell with arched dorsum and broadly rounded anterior. Shell depressed dorsally in front of hinge area and in dorsal view, oval in shape. Greatest height just before mid-length; convex area of the ventrum behind mid-length. Left valve slightly larger than right valve all along. Selvage thin and peripheral on both valves except in the posteroventral area of right valve.

**Ecology:** This rare species inhabits highly saline lakes in which halophytes cannot grow. Its salinity range for this species in the lakes adjacent to the Coorong Lagoon in South Australia is 14-195°/∞ (De Deckker & Geddes 1980). The low salinity records were taken during winter when water was plentiful for a short period of time and consequently water salinity temporarily reduced. This species has not yet been recorded living in Victoria.

**Remarks:** Only a few valves of this species have been found in one sample each from Lakes Keilambete (KG 410) and Gnotuk (GH 315). It is distinguished from the other *Diacypris* species by its more rectangular outline and oval shape in dorsal view.

**Ilyocypris australiensis** Sars 1889
Fig. 12Z, AA-II

1889 *Ilyocypris australiensis* Sars, p. 46.

**Description:** Adult: rectangular and pitted shell occasionally covered with fine denticles especially along periphery; 3 main depressions on shell; a central round one, another round one above it and below the hinge line and a third one vertically enlogated in front, starting below the hinge line and ending at mid-height between the other 2. Greatest height at about 1/4 from anterior. Hinge adont. Inner lamella broadest anteriorly and selvage broad all along in both valves. Juvenile: compared to adults, length height ratio of valves greater and height of shell of the hinge much greater than at posterior.

**Ecology:** *I. australiensis* occurs in temporary freshwater pools but it has been found in slightly saline lakes in Victoria. In the latter, it is usually found at salinities ranging between 4 and 7°/∞. The uppermost salinity record of 10.37°/∞ is from Lake Kariah.

**Remarks:** The ornamentation of the shell of *I. australiensis* is very variable: the shell can be nearly smooth, faintly spinose or reticulated all over. For further details, see De Deckker (1981a).

**Leptocythere lacustris** De Deckker 1981
Fig. 12A-O

1981a *Leptocythere lacustris* De Deckker, p. 129.

**Description:** See De Deckker (1981a).

**Ecology:** *L. lacustris* is a benthic species which requires permanent water conditions. Its salinity range is 19-28°/∞ with one collection at 2.8°/∞. Being of marine ancestry its salinity range probably extends up to 35°/∞; for more detail see De Deckker (1981a).

**Remarks:** The shell ornamentation of *L. lacustris* varies from almost smooth to coarsely reticulated.

**Limnocythere dorsosicula** De Deckker 1981
Fig. 12Q-X

1981b *Limnocythere dorsosicula* De Deckker, p. 43.

**Description:** See De Deckker (1981b).

**Ecology:** This species is known from four localities: two in Victoria (Lake Terangpom and South Nerrin Nerrin Lagoon) and two in New South Wales (Lake Bathurst and The Morass). Its salinity range is 0.42-3.3°/∞ and therefore indicates fresh or slightly

FIG. 6—Distribution of fossil remains and grains in the upper part of core BK from Lake Bullenmerri. Numbers in the ostracod columns are the number of ostracod valves recovered per 3 gm of sediment. Triangles indicate the position of samples taken from the core. Underlined dates are those which were obtained from core BK, others were obtained by correlation with other dated cores.

Fig. 6—(*continued*) Distribution of fossil remains and grains in the lower part of core BK from Lake Bullenmerri.

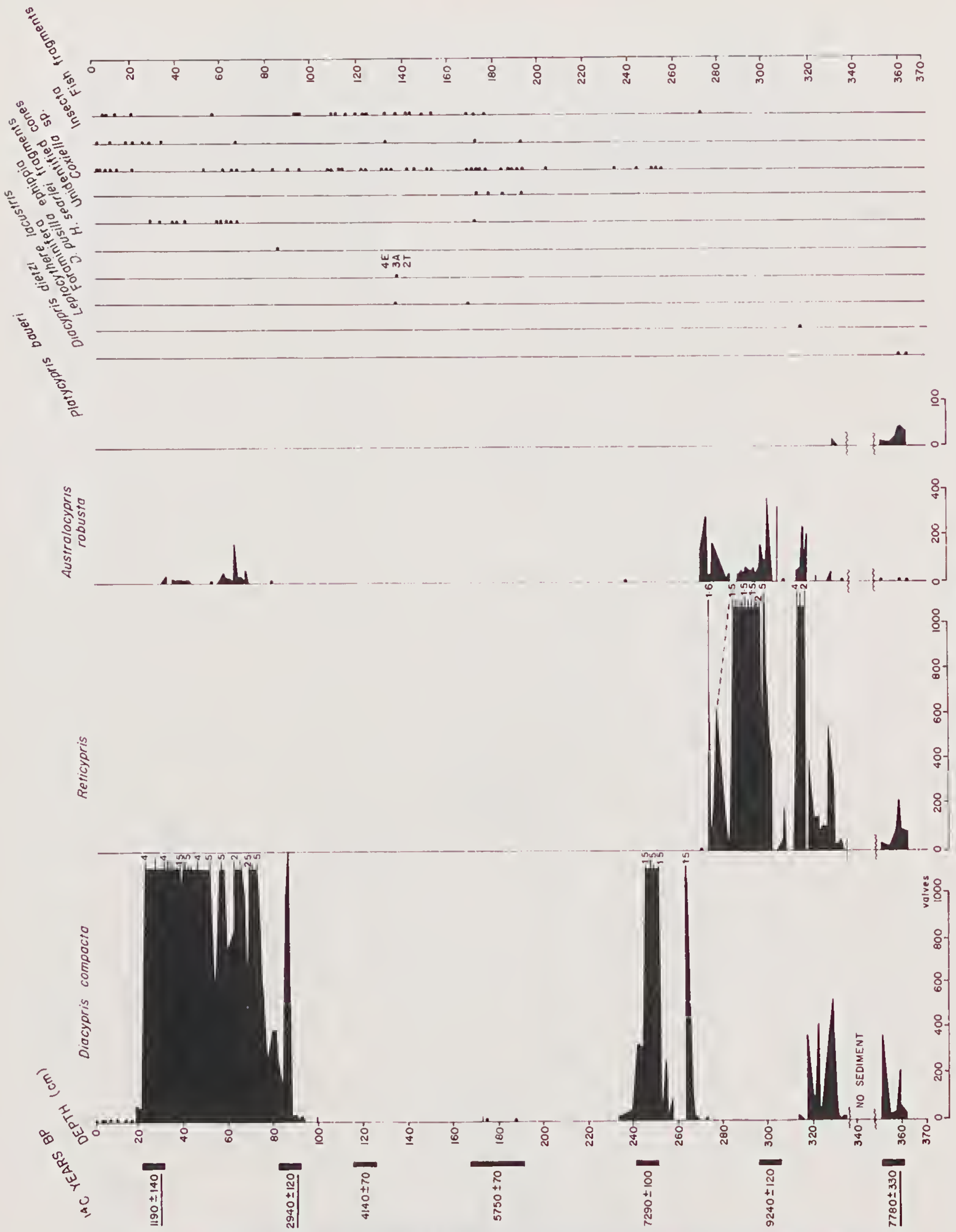


FIG. 7—Distribution of fossil ostracods and other remains in core GH from Lake Gnotuk. Numbers in the ostracod columns are the number of ostracod valves recovered per 3 gm of sediment. Dots in the other columns refer to the presence of remains recovered only in low numbers. In Foraminifera column: E = *Elphidium* sp., A = *Ammonia beccarii*, T = *Triloculina rotunda*. For $^{14}C$ dates, refer to the text and caption of Fig. 6. The underlined dates are those obtained from core GH.

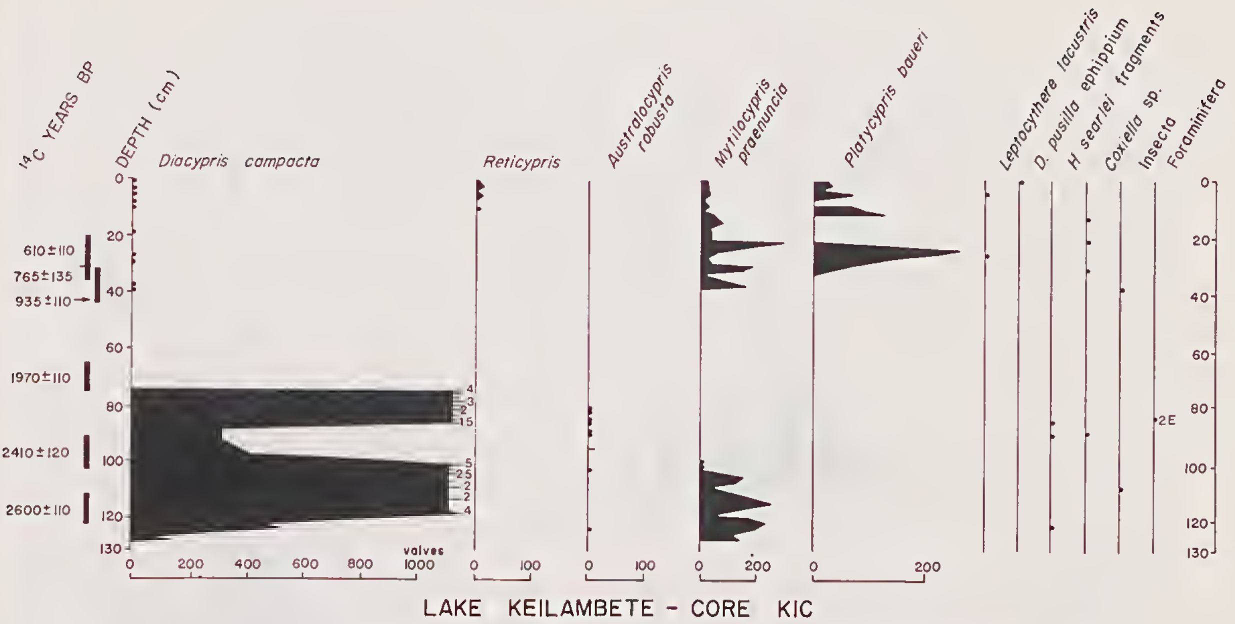


Fig. 8—Distribution of fossil ostracods and other remains in core KIC from Lake Keilambete. Some remarks as for Fig. 7 except for Foraminifera column.

saline water. Very likely it requires permanent water conditions.

**Mytilocypris praenuncia** (Chapman 1936)
Fig. 13A-L

1936 *Cypris praenuncia* Chapman, p. 298.
1978 *Mytilocypris praenuncia*; De Deckker, p. 24.

Description: Adult: valves large (ca. 3 mm), smooth, fairly thin, subtriangular in shape with a steeply inclined dorsum. Greatest height at about 0.3 from anterior; posteroventral area of shell broadly curved in lateral view. Inner lamellae broad anteriorly and posteriorly. Juvenile: more triangular in shape with posteroventral area more pointed; distance of greatest height from anterior between 0.3 and 0.5 of length.

Ecology: *M. praenuncia* can swim easily but is often seen on the lake floor or in among beds of halophytic plants such as *Ruppia* sp., *Lepilaena* sp. and the charophyte *Lamprothamnium papulosum*. Its salinity range varies between 5 and 42°/oo in Victorian waters. The same species has previously been recorded in the Coorong area (De Deckker & Geddes 1980) at salinities between 12 and 35°/oo with one additional record at 43°/oo. It is usually found in samples with *P. baueri* and can occur with *Diacypris spinosa* (salinity range: 5-16°/oo) at lower salinities. As the latter species has never been found in the cores studied here the records of the fossil *M. praenuncia* probably represent the upper part of the salinity range of the species. The presence of *M. praenuncia* indicates waters of much lower salinities than for *A. robusta*.

Remarks: *M. praenuncia* may be distinguished from *A. robusta* by its very obvious triangular shape, its broader inner lamella and its more compressed outline in dorsal view. Remarks made for large concentrations of shells of *A. robusta* on shore lines also apply for this species.

**Platycypris baueri** Herbst 1957
Fig. 13Z, AA-LL

1957 *Platycypris baueri* Herbst, p. 217.

Description: Adult: valves smooth, very thin and oval to rectangular in shape; greatest height at about 0.6 from anterior. Slightly concave ventrum about 0.3 from anterior. In dorsal view, valves very narrow. Inner lamella almost non-existent posteriorly and broad only in the anterodorsal margin. Muscle scar area minute. Juvenile: oval in largest to almost circular in smallest specimens. Faint concavity in ventral area also present 0.3 from anterior.

Ecology: *P. baueri* is a good swimmer but it also burrows into soft lake sediments. It has the broadest salinity range of any ostracod found in Australia; in Victorian lakes it is 9.3-176°/oo (Geddes 1976) and 5-182°/oo (De Deckker unpubl.) and for the lakes near the Coorong Lagoon it is 5-195°/oo (De Deckker & Geddes 1980). This species occurs in low numbers at low salinities and usually is much more abundant at salinities above approximately 70°/oo (Geddes 1976, De Deckker & Geddes 1980). High water salinity of the order of 100±50°/oo is inferred when fossil *P. baueri* is found with no other ostracod species or only with *A. robusta*. On the other hand when fossil *P. baueri* is found with *M. praenuncia*, water salinity is thought to be of the range of the latter species, viz. 20-43°/oo.

Remarks: Some specimens of *P. baueri* were recovered from the cores with both valves still attached in the hinge area (Fig. 13FF). This is surprising as valves, especially for this species, become separated fairly rapidly after death of the animal. It is suggested that these fossil carapaces belong to animals which were burrowing

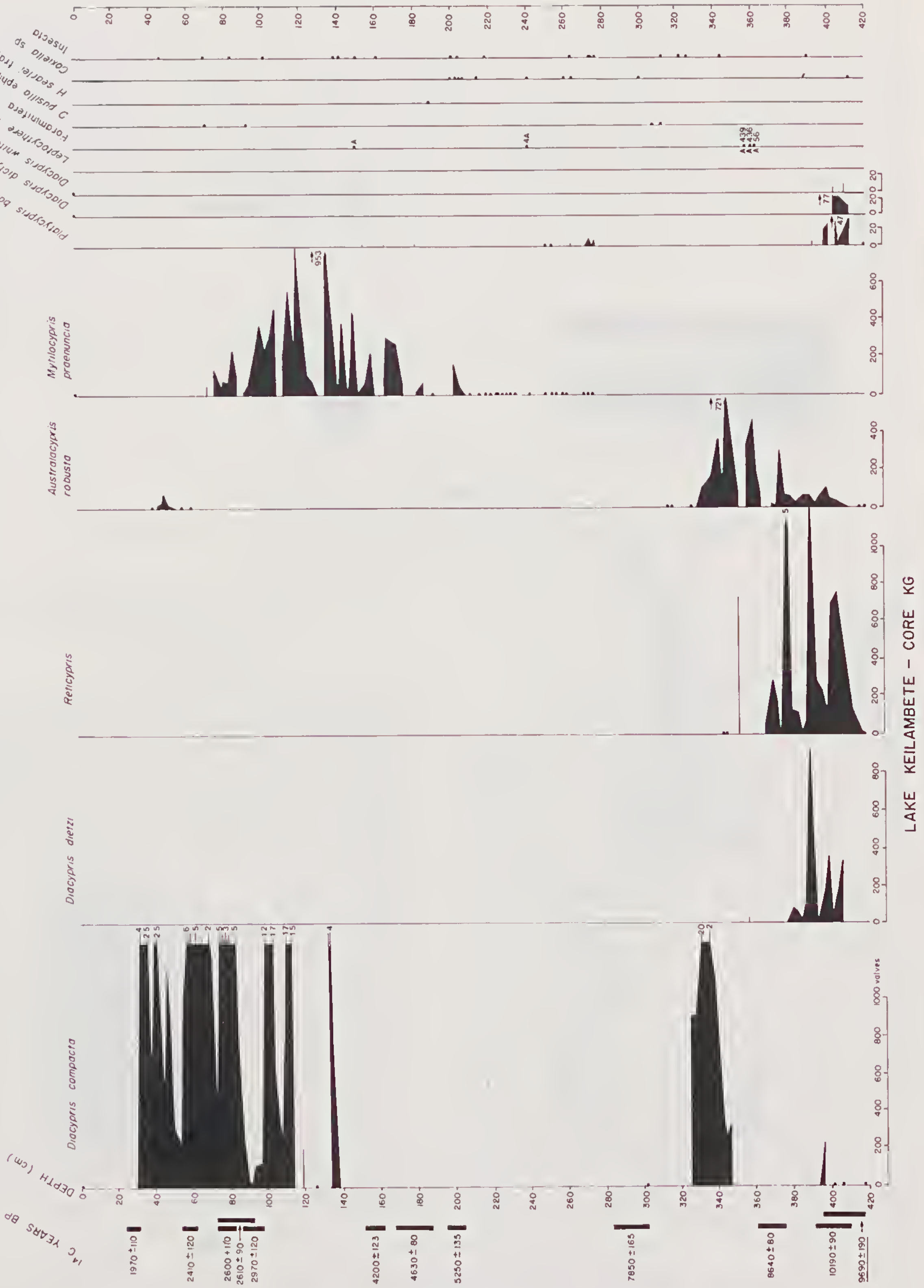


FIG. 9—Distribution of fossil ostracods and other remains in core KG from Lake Keilambete. Some remarks as for Fig. 7 except that for $^{14}$C dates, refer to Table 3. The underlined date is the only one obtained from core KG.

FIG. 10—Distribution of fossil remains and grains in core PC from Lake Purrumbete. Dots indicate the position of samples taken from the core. Triangles indicate only the presence of remains and grains in the core.

FIG. 11—Lake-level curves for Lakes Bullenmerri and Purrumbete, and salinity-level curves for Lakes Gnotuk and Keilambete postulated from the data obtained from fossil ostracods and other remains. These curves are compared with the water-level curve for Lake Keilambete of Bowler (1981).

in sediments and remained there until death. These ostracods are likely to be of a younger age than the other organisms found with them in the samples. There is however no way of controlling this possible discrepancy, unless signs of bioturbation are observed, and it will be ignored here as only few carapaces of *P. baueri* have been recovered in the cores.

### Genus **Reticypris** McKenzie 1978

The species *R. herbsti* McKenzie 1978 and *R. clava* De Deckker 1981 are easily recognized on anatomical features but may not be distinguished on shell character alone. However, their fossils recovered from Lakes Gnotuk and Keilambete cores have been identified at the specific level because of their association with other ostracod species (see discussion on ecology below). The descriptive notes refer to both species.

### **Reticypris** spp.

Fig. 14A-T, LL-MM

Description: Adult: shell subrectangular with dorsum slightly arched; valve reticulated all over except along periphery; inner lamellae broader anteriorly; greatest height of shell between 0.3 and 0.5 from anterior. Left valve larger than right one with often obvious overlap of left valve in the dorsal area. Juvenile: often shell more circular to subtriangular in shape; reticulation on shell more patchy (Fig. 14O-Q). In some specimens, ventral ridge visible on both valves.

Ecology: In collections from Victorian lakes, *R. clava* always accompanied low salinity tolerant ostracods such as *Mytilocypris splendida* or *M. praenuncia* and occasionally *Diacypris spinosa*. Salinity for these collections ranged between 4 and 42°/oo. *R. herbsti*, on the other hand, was collected in other lakes in Victoria with *D. compacta* at salinities between 99 and 172°/oo. Therefore, the absence of *D. compacta* and presence of either a *Mytilocypris* species or *D. spinosa* as fossil with *Reticypris* valves should help in identifying *R. clava*. The opposite association would point out to the presence of *R. herbsti*.

In the lakes near the Coorong Lagoon, data for both *Reticypris* species are less clear: the salinity range for *R. clava* was 5-131°/oo but it was never found in high numbers above 68°/oo; for *R. herbsti*, the salinity range was 12-141°/oo with 3 additional records at 195, 216 and 218°/oo (De Deckker & Geddes 1980). The latter species occurred in high numbers between 104 and 124°/oo. Apart from the broader ranges for each species, the salinity values at which each species was found in high numbers is similar to that for the Victorian specimens. The latter values from Victoria are used here for the interpretation of the cores.

## Foraminifera

Foraminifers have recently been recognized as common benthic inhabitants of salt lakes in Australia (De Deckker & Geddes 1980, Cann & De Deckker 1981). Although they may prefer salinities close to that of sea water they "survive" fluctuating salinities and some even withstand periods of lake desiccation (Cann & De Deckker 1981). Their transport into lakes like that for ostracods is probably by birds (De Deckker 1977).

Some of the foraminifer species found in the cores can survive periods of desiccation, e.g. *Elphidium* sp. *sensu* Cann & De Deckker (1981) whereas others apparently cannot as they are only found in permanent water e.g. *Ammonia beccarii* and *Triloculina rotunda*.

### **Ammonia beccarii** (Linné 1758)

Fig. 15W-Z, AA-FF

1758 *Nautilus beccarii* Linné, p. 710.

1949 *Ammonia beccarii*; Frizzell & Keen, p. 106.

Description: Finely perforated, trochospiral text more convex dorsally; sutures usually thick and smooth; ventrally gradation of umbilicus from empty to a plug and often finely to coarsely spinose. Some aberrant growth forms (Fig. 15BB, FF) have been found in some samples.

Ecology: This cosmopolitan species indicates a salinity close to that of sea water, although it is known to survive a broad range of salinities, from 7-67°/oo (Bradshaw 1957). It only reproduces and grows best at salinities between 20-40°/oo (Bradshaw 1957). At level 362-367 cm in core KG from Lake Keilambete, the large number of specimens of all sizes of *A. beccarii* represent a series of thriving populations and indicates a salinity similar to that of sea water.

### **Discorbis** sp.

Fig. 15GG

Remarks: One specimen was found at level GH135 in the Lake Gnotuk core. This species has not been found in present day salt lakes.

### **Elphidium** sp. *sensu* Cann & De Deckker 1981

Fig. 15Q-R, U-V

Description: See Cann & De Deckker (1981).

Ecology: The salinity range of this species is not yet known although it is known to "survive" high salinities: at 88°/oo no pseudopodia were seen protruding from the test but the same specimens, put in sea water, became active (Cann & De Deckker 1981).

### **Triloculina rotunda** d'Orbigny 1893

Fig. 15S-T

1893 *Triloculina rotunda* d'Orbigny, p. 20.

Description: Test triloculine, oval in shape, flattened at aperture and ellipsoidal in section. Aperture with narrow bifid tooth.

Ecology: This species is rare in the core samples and has only been collected in a lake with a salinity range of 17-24°/oo and in permanent water. *T. rotunda* was never found in the ephemeral Coorong lakes samples, collected over a year by De Deckker & Geddes (1980).

## Mollusca

Only shells (no opercula) of the halobiont gastropod *Coxiella* sp. have been recovered in the cores. The gastropod *Potamopyrgus niger* (Quoy & Gaimard 1835) and the bivalve *Sphaerium* sp., are both found today in Lake Purrumbete (Timms 1981) and their absence in the cores has some relevance to the lake histories.

### **Coxiella** sp.

Fig. 17P-Z, DD-EE

Description: Conical to elongate shell with up to 7 whorls; round to oval aperture with broad lip in adults; extent of umbilicus variable; shell finely ribbed and sutures deep. Up to 10 mm in length.

Ecology: Species of *Coxiella* can withstand lake desiccation phases and also survive high salinity ranges by sealing their aperture with the operculum. No salinity information can be obtained from their fossils except that they exclude fresh water as *Coxiella* is a halobiont genus. In lakes below 100°/oo salinity *Coxiella* spp. often graze on algal mats or crawl in among halophytic grasses such as *Ruppia* sp., *Lepilaena* sp. and the charophyte *Lamprothamnium papulosum*. Live specimens of *Coxiella* have never been found at great water depths: in Lake Bullenmerri, Timms (1973, 1981) collected juveniles (length <5 mm) of *Coxiella striata* (Reeve 1842) down to 25 m and larger specimens of the same species rarely below 6 m. He also recorded large numbers of emptied juvenile shells between depths of 12 and 25 m. Consequently, a large concentration of adult *Coxiella* shells in cores (e.g. 201.5-202.5 cm in core KG from Lake Keilambete) very likely indicates that lake depth was probably less than 25 m and most probably less than 6 m.

After death of the animals, shells become filled with gas resulting from body decay and float and are often blown by the wind onto the lake shore. As a result extensive layers of *Coxiella* shells are common on many lake shores. Such layers should easily be recognized in cores. Juveniles of *Coxiella,* on the other hand, have been seen to float upside down at the surface tension in some lakes. Their failure to remain near the surface and subsequent death by sinking to the bottom of the lake, would explain the presence of few shells of juveniles found in a number of samples: their occurrence in sediments in this case adds no information on the depth of the lake at the time of their death.

Remarks: As pointed out by Mellor (1979) and De Deckker & Geddes (1980), the taxonomy of all *Coxiella* species is in a confused state. Doubt is now placed on the value of previously considered diagnostic features of the shell and this is the reason for which no specific identification is attempted here. See Fig. 17P-Z for an illustration of variations in shell morphology.

Timms' data (1973, 1981) on *C. striata* found living in Lake Bullenmerri today are used to interpret the fossil material. Ecological requirements are likely to be similar for both fossil and living material.

Chapman (1919) identified the fossil *Coxiella striatula* (Menke 1842) from the Pleistocene (*sic* Chapman 1919) deposit at Boneo Swamp in Victoria but gave no consideration to the fact that it is found with other molluscs, apparently freshwater inhabitants.

The freshwater gastropod *Potamopyrgus niger* (Quoy & Gaimard 1835) occurs in Lake Purrumbete (Timms 1973, 1981) over a wide depth range (0.5-35 m) but is most common between 1 and 6 m (Timms 1973). As this gastropod was never recorded in any of the cores, it appears that especially in the case of Lake Purrumbete, which is thought to have remained fresh for the period represented in the entire core, the shore of the lake has never been close to the coring site, otherwise shells of *P. niger* would have been found. This remark also applies to the freshwater bivalve *Sphaerium* sp., found today in Lake Purrumbete between 0.5 and 22.5 m in depth (Timms 1981) but never recovered in any of the cores.

### CLADOCERA

Only ephippial sac remains have been recorded from the cores—cuticular fragments of cladocerans were noticed in some samples but were not studied further. Two main types of ephippium were found: one belonging to the halobiont *Daphniopsis pusilla* and the other to the mainly freshwater inhabitant *Daphnia* spp.

### **Daphniopsis pusilla** Serventy 1929

Fig. 16A-D

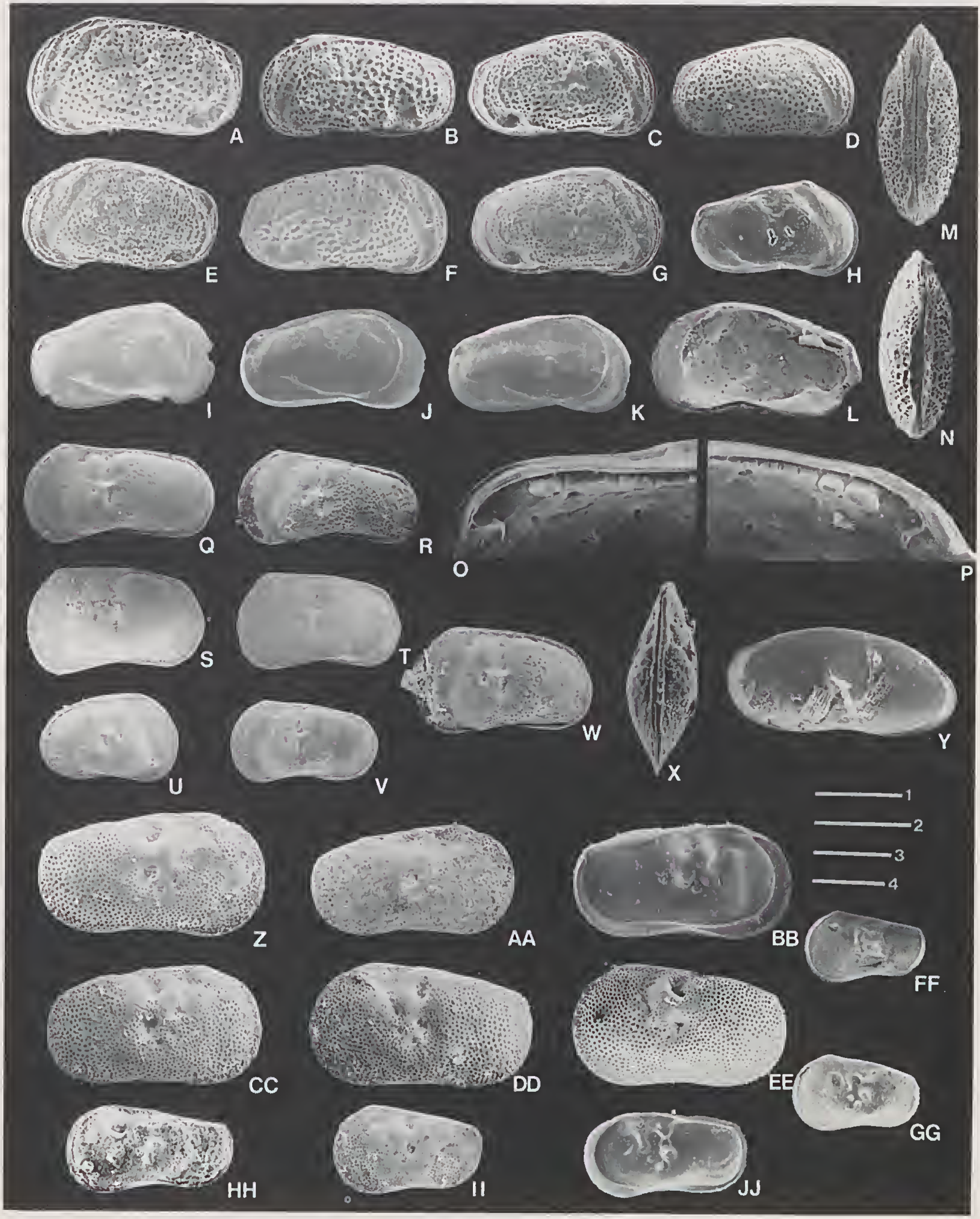
1929 *Daphniopsis pusilla* Serventy, p. 65.

Description of ephippium: Ephippial sac almost rectangular and asymmetrical: posterior side forming almost a right angle with small extension of dorsal chitinous rod (which is occasionally bifid) whereas anterior side forming an acute angle with the longer and often bifid chitinous rod. Greatest length of ephippial sac at about 0.65 from its dorsal side. In dorsal view, very compressed.

Ecology: The ecology of *D. pusilla,* which is endemic to Australia, has been recently reviewed by De Deckker & Geddes (1980). The salinity range of this cladoceran in the lakes near the Coorong is 5.8-68.1°/oo, although few specimens were recorded at the 68.1°/oo. Geddes (1976) noted that hatching of the species occurred between 4.4 and 33.4°/oo. The presence of ephippial sacs at a particular level in a core should imply that the lake water had been at some stage between 4.4 and 33.4°/oo for that level. On lake floors today, occasional bundles of 20 or more ephippial sacs of *D. pusilla* entangled together by the bifid chitinous rods are found. This phenomenon was not observed in fossil material.

Remarks: The most diagnostic feature of the ephippium for this species is the acute angle formed by the anterior dorsal chitinous rod and the anterior side of the ephippial sac.

Fig. 12—A-O, *Leptocythere lacustris* De Deckker 1981. A, LV external, BK 159. B, LV external, BK 210. C, RV external, KIC 27. D, RV external, BK 210. E, LV external, GH 135. F, RV external, BK 177. G, RV external, GH 135. H, LV internal, KIC 5. I, LV internal, BK 187. J, LV internal, BK 210. K, LV internal, BK 210. L, RV internal, BK 187. M, C dorsal, GH 135. N, C dorsal, GH 135. O, LV internal, hinge posterior of I. P, LV internal, hinge anterior of I. Q-X, *Limnocythere dorsosicula* De Deckker 1981. Q, LV external, male, BK 187. R, LV external, male, BK 171. S, LV external, female, BK 210. T, LV external, female, BK 206. U, RV external, juvenile (female?), BK 210. V, LV external, juvenile (male?), BK 210. W, LV external, female, BK 175. X, C dorsal, BK 182.5. Y, *Candonocypris novaezelandiae* (Baird 1843), RV internal, juv., BK 17. Z, AA-II, *Ilyocypris australiensis* Sars 1889. Z, RV external, BK 187. AA, RV external, BK 187. BB, LV internal, BK 470. CC, RV external, BK 210. DD, LV external, BK 210. EE, LV external, BK 472. FF, RV internal, juv., BK 193. GG, LV external, juv., BK 158. HH, RV internal, juvenile male, BK 206. II, RV internal, juv., BK 189. JJ, RV internal, juv., BK 193.
Scales: 1-200 μm for A-N; 2-50 μm for O-P; 3-200 μm for Q-Y; 4-250 μm for Z-JJ. Note: BK, GH, KIC, GH, PC = Core label followed by depth in cm from top of core. C = carapace; LV, RV = left and right valves; juv. = juvenile.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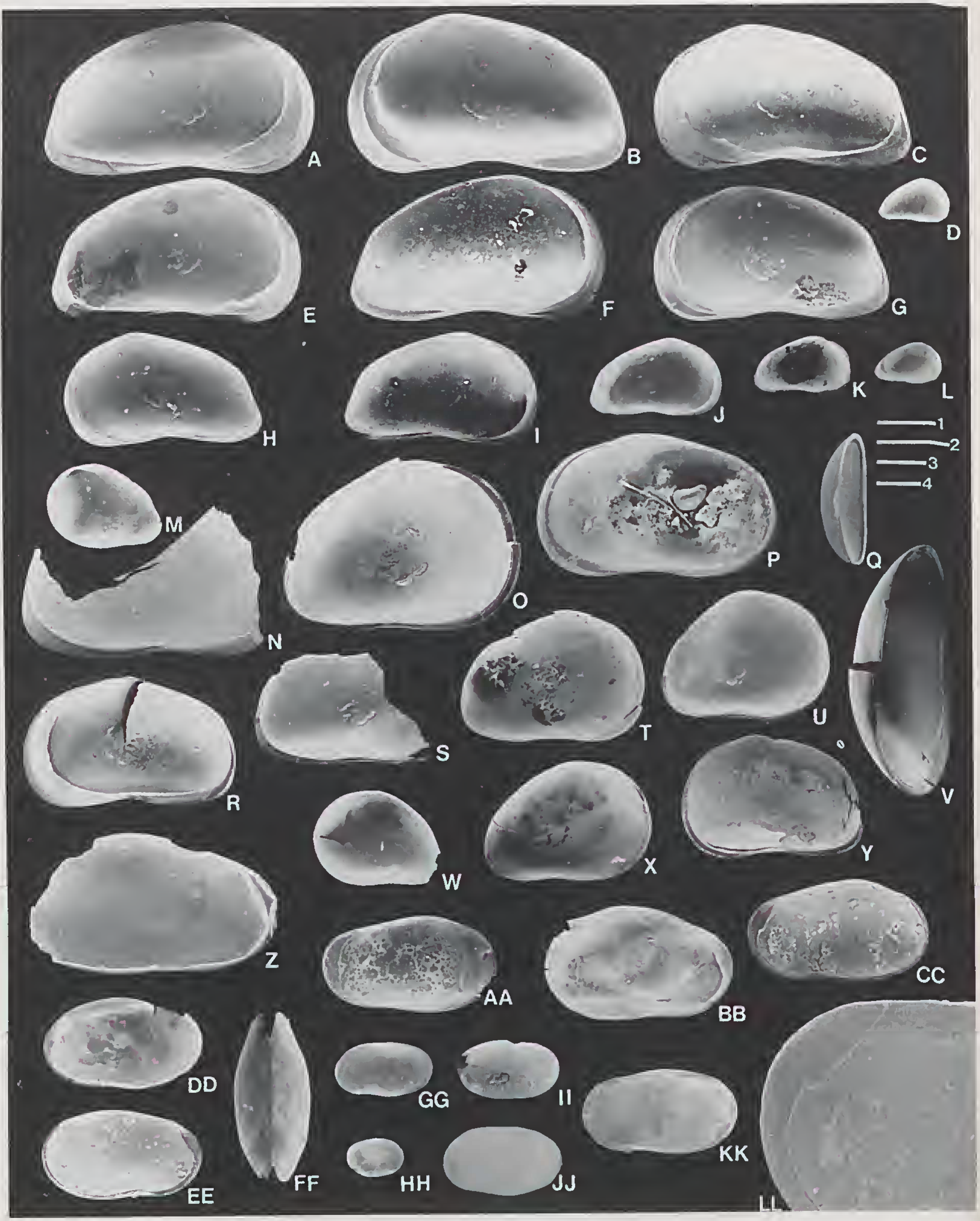
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### **Daphnia** spp.
Fig. 16E-H

Description of ephippium: Epphipial sac ellipsoid in shape and at least twice as long as wide; in dorsal view narrow to bulbous; external surface sometimes faintly reticulated. Dorsal chitinous rod longer anteriorly and forming a right angle with posterior side of the ephippial sac; posterior angle obtuse. Internal capsule often with a ridge along its periphery (broadest anteriorly and posteriorly) and with a vertical groove in the middle separating the two egg spaces; external surface of capsule reticulated.

Ecology: No identification at the species level of ephippial sacs of daphniid species is yet possible. Their presence, however, indicates a water salinity between fresh and 5.8°/∘∘. The upper record refers to a collection made in January 1980 from a small lake near Lake Coragulac in Victoria. Five records of *Daphnia* spp. observed in a survey of 79 lakes during the same period, ranged between 1.90 and 4.91°/∘∘. *Daphnia carinata* King 1853 was recorded by Geddes *et al.* (1981) from three localities in Western Australia where salinity values ranged between 3.57 and 4.76°/∘∘. The value of 5.8°/∘∘ is the upper value recorded so far in Australia for a *Daphnia* species and it will be regarded as the maximum value for the fossil material studied here.

Remarks: Sars (1885) accurately illustrated the morphology of the ephippium of *D. lumholtzii* Sars 1885 by providing adequate illustrations of ephippial sacs and internal egg capsules. These resemble the material recovered from the Lakes Bullenmerri and Purrumbete cores, but the latter deflated or partly shrunk after the drying process prior to picking and preparation for SEM photography. However, Sars' illustrations show a double row of tiny spines along the dorsal chitinous rod attached to the ephippial sac. These were rarely seen on the specimens recovered from the cores (e.g. Fig. 16F). No further identification has been carried out.

## Isopoda

Remains of the aquatic halobiont isopod *Haloniscus searlei* have been recovered from a number of core samples and are described below.

### **Haloniscus searlei** Chilton 1920
Fig. 15HH-PP

1920 *Haloniscus searlei* Chilton, p. 724.

Description of remains found in the cores:

*Cones:* Slightly curved and hollow, partly calcareous? and brittle; external surface consisting of parallel rows of disconnected and alternating faint and arched grooves; some with occasional rimmed triangular pores with two small pores inside and one at base of triangle. The cones with pores correspond to distal segments of the posterior appendages of the animal, and those without pores belong to spines attached to the telson.

*Others*: These are of various shapes and are illustrated in Fig. 15KK-PP. The fragment illustrated in Fig. 15MM is a proximal segment of one of the appendages whereas fragments illustrated in Fig. 15NN-PP are thought to be part of ventral parts of the animal's head. In most cases, the external surface of these fragments is characterized by faint grooves similar to those found on the cones (Fig. 15HH-II).

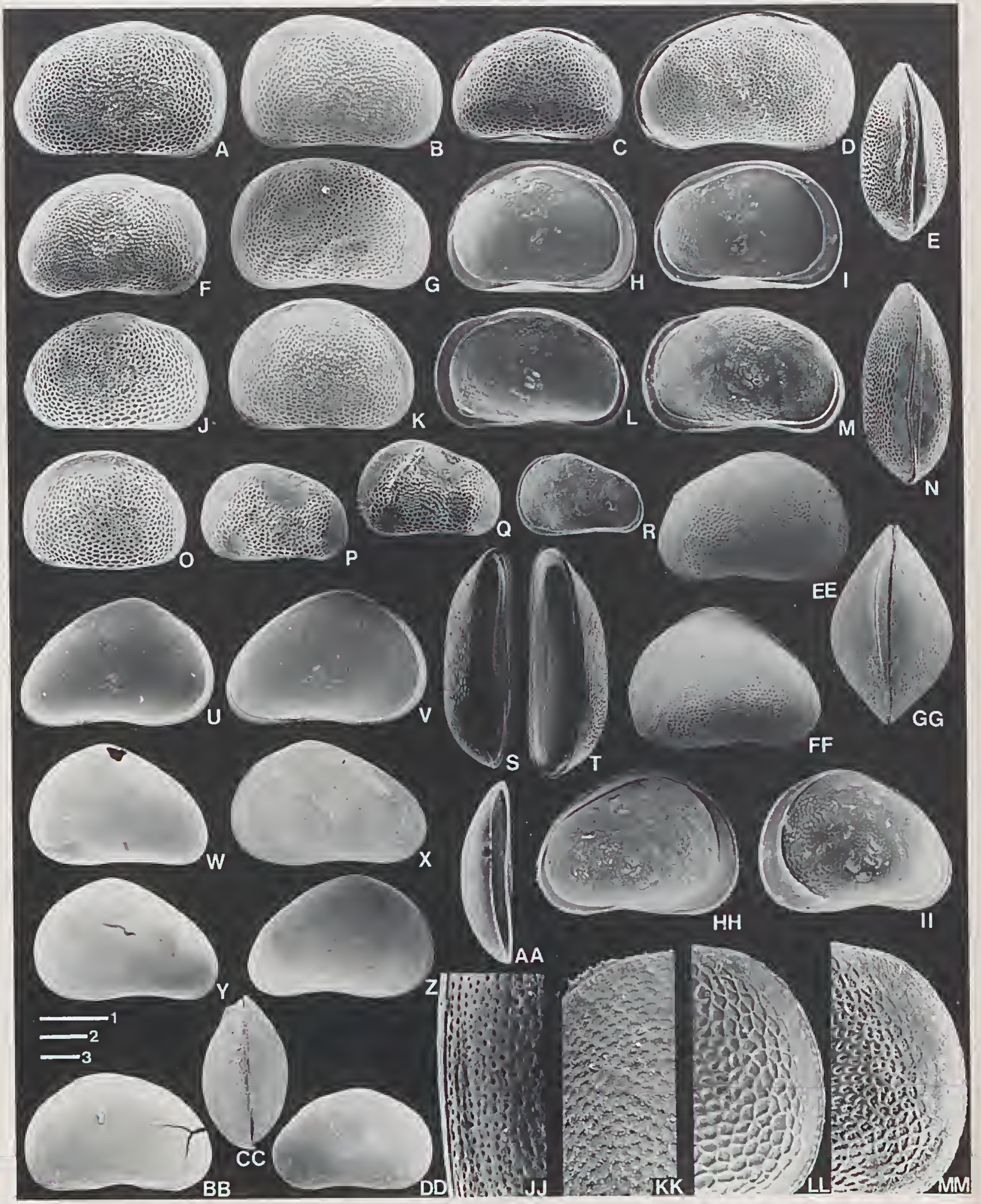
Ecology: The biology of *Haloniscus searlei* has been thoroughly reviewed recently by Williams (in prep.). It is an Australian endemic oniscoid isopod which is aquatic and tolerates a high range of water salinities: 3.6-191.7°/∘∘. It is also known to survive periods of lake desiccation (De Deckker & Geddes 1980, Williams in prep.).

Remarks: Similar fragments have been found in other lacustrine deposits (Pillie Lake in South Australia) (De Deckker *et al.* 1982). Their presence cannot provide much ecological information as *H. searlei* is found in both ephemeral and permanent saline lakes. Although *H. searlei* occurs in ephemeral lakes, annual rainfall is necessary each year for the animal to survive as it cannot survive complete desiccation (Ellis & Williams 1970). This explains its absence in Central Australian lakes which are dry for long periods.

## Porifera

Only three specimens of the asexual reproductive bodies of spongillid sponges have been recovered from the Lake Purrumbete core. These gemmules are all distinct and will be briefly described below. They all

Fig. 13—A-L, *Mytilocypris praenuncia* (Chapman 1936). A, LV internal, KG 135.5. B, RV internal, KG 135.5. C, RV internal, KG 135.5. D, RV external, juv., KG 201.5. E, LV internal, KG 164.5. F, LV internal, KG 181.5. G, RV internal, KG 181.5. H, RV internal, juv., KG 201.5. I, LV internal, juv., KG 135.5. J, LV internal, juv., KG 135.5. K, LV internal, juv., KG 135.5. L, RV external, juv., KG 135.5. M-Y, *Australocypris robusta* De Deckker 1974. M, LV external, juv., KG 380. N, LV internal, fragment, GH 62.5. O, LV internal, juv., KG 362. P, RV internal, GH 300.5 (note juvenile *Diacypris* sp. inside). Q, LV dorsal, juv., KG 377. R, RV internal, KG 362. S, LV internal, fragment, KIC 95. T, RV external, juv., KIC 95. U, LV internal, juv., KIC 95. V, LV dorsal, juv., KG 360. W, LV external, partly broken, juv., KG 360. X, RV external, juv., KG 360. Y, RV internal, partly broken, KG 360. Z-LL. *Platycypris baueri* Herbst 1957. Z, LV internal, partly broken, juv., KG 274. AA, RV internal, partly broken, KG 404. BB, LV internal, partly broken, KG 404. CC, RV internal, KG 404. DD, RV internal, juv., KG 393. EE, LV internal, juv., KG 393. FF, C dorsal, KIC 26. GG, LV external, juv., KIC 26. HH, LV external, juv., KIC 26. II, RV external, juv., KIC 26. JJ, LV external, ? juv., KIC 26. KK, LV external, KIC 26. LL, RV internal, anterior detail of CC.
Scales: 1-1 000 μm for A-L, N, P-T, Y; 2-500 μm for M, U, AA-KK; 3-500 μm for O and 250 μm for V; 4-100 μm for LL.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belong to the Australasian genus *Heterorotula* Penney & Racek 1968. All three indicate freshwater conditions as none respond to the description of *H. capewelli* (Bowerbank 1863) which is known to tolerate athalassic saline environments from Central Australia to the Dividing Range (Racek 1969).

*Heterorotula nigra* (Lendenfeld 1887) (Fig. 16P-R) is distinguished by the usually granulated gemmoscleral shafts and the absence of megascleres from the pneumatic layer. The foramen has not been examined.

*Heterorotula multidentata* (Weltner 1895) (Fig. 16O-T) is recognized here by its smooth to microspined megascleres and the occasional reinforcement of the outer coat of the pneumatic layer by megascleres. The foramen is simple and bears no collar.

The gemmule of *Heterorotula* sp. (Fig. 16N,S) resembles *H. capewelli* as many megascleres are present around its periphery. It is distinguished from the latter species on the following details: the gemoscleres are present only on the outside of the pneumatic layer in *H. capewelli* (for comparison see Penney & Racek 1968, Plate 8, Fig. 5); the megascleres in *H.* sp. are more pectinate and the edge of the gemmosclere rotules is spinose rather than crenulate as in *H. capewelli.*

REMARKS: Few megascleres, cemented on trichopteran cases were noticed in samples from the Lake Purrumbete core (Fig. 17FF-HH). These belong to *Heterorotula* spp., and although megascleres recovered from lacustrine sediments can provide some palaeoecological information as already demonstrated by Racek (1966) for Guatemalan material, no similar attempt was made to systematically recover spongillid remains.

No remains of *Radiospongilla sceptioides* (Haswell 1882) have been found in the cores even though the species has been recorded twice from Lake Purrumbete (Nov. 1969, May 1970) by Timms (1973, 1981).

### VERTEBRATA

Four types of fish remains were recovered from the cores: jaw bones, scales, otoliths and other bone fragments. Only some items of the first type could be identified and subsequently provide palaeoecological information. The other remains in lakes Bullenmerri, Gnotuk and Keilambete, which are not connected to rivers indicate permanent water when fish were present.

Two categories of jaws are recognized: those with a single or a double row of teeth (Fig. 17A-C, F-G) and those with more than two rows along most of their length (Fig. 17E, I-J). For their classification see Table 2. Also a few remains bearing teeth (Fig. 17D, H, L) are identified as being part of the mouth of fishes—they usually consist of straight rods with fewer teeth and occasionally have a flat base (Fig. 17D); others are large vomer plates covered with many teeth (Fig. 17H). Only the latter could not be identified at the generic level.

Table 2 lists also the species which are found today in Lakes Bullenmerri and Purrumbete. In addition, the hardyhead *Craterocehalus stercusmuscarum* (Guenther 1867) is also listed as it is a common inhabitant of slightly saline lakes in Victoria. The following palaeoecological information can be obtained from the fossil material: jaws with more than two rows of teeth belong to fish which live in water of salinities between <3 and 13.4°/oo; for the other jaws, the salinity range referred to lies between <3 and 30.3°/oo.

Although Lake Gnotuk is devoid of fish today very likely fish would more easily be introduced in it, compared to Lake Keilambete, as the former lake can receive overflowing waters from the adjacent less saline Lake Bullenmerri. The record of two fish species (see Table 2) from Lake Gnotuk in 1916 probably resulted from the last overflow recorded in 1841. As the lake level dropped continuously since 1841 (Currey 1970), salinity would have progressively increased and eventually fish would not have been able to survive the highly saline waters such as those found today. Salinity of Lake Gnotuk was between 3-13.4°/oo at the time of deposition of level 6.5 cm (see Fig. 7), a period probably following an overflow from Lake Bullenmerri as jaws with more than two rows of teeth are found in the samples. Such an overflow must have occurred on a number of occasions since fish remains are sparsely distributed in the upper 200 cm of the Lake Gnotuk core.

### DIPTERA-CHIRONOMIDAE

Head capsules, mandibles and labia of chironomid larvae can be useful in tracing past changes of lake productivity as a number of chironomid species are very sensitive to changes of sediment types and oxygen concentration. The only work dealing with the recovery of chironomids in Australia is that of Paterson & Walker

FIG. 14—A-T, LL-MM, *Reticypris*. A, RV external, KG 372. B, LV external, KG 372. C, C showing RV, juv., KG 372. D, C showing RV, KG 372. E, C dorsal, KG 372. F, RV external, KG 372. G, LV external, KG 351.5. H, LV internal, KG 372. I, LV internal, KG 351.5. J, RV external, KG 372. K, LV external, KG 372. L, RV internal, KG 351.5. M, RV internal, KG 351.5. N, C ventral, KG 351.5. O, LV external, juv., KG 372. P, LV external, juv., KG 372. Q, LV external, juv., KG 372. R, RV internal, juv., KG 351.5. S, LV dorsal, KG 351.5. T, RV dorsal, KG 351.5. LL, RV external, anterior detail of J. MM, RV external, anterior of F. U-Z, AA, JJ, *Diacypris dietzi* (Herbst 1958). U, LV internal, KG 393. V, LV internal, KG 393. W, LV external, KG 398.5. X, LV external, KG 398.5. Y, LV external, KG 398.5. Z, RV external, KG 398.5. AA, LV dorsal, KG 398.5. JJ, LV external, anterior detail of U. BB-DD, *Diacypris whitei* (Herbst 1958). BB, LV external, KG 410. CC, C dorsal (note valves dislocated), KG 410. DD, RV external, KG 410. EE-II, KK, *Diacypris dictyote* De Deckker 1981. EE, RV external, KG 410. FF, LV external, KG 410. GG, C dorsal, KG 410. HH, LV internal, KG 410. II, RV internal, KG 410. KK, LV external, anterior detail of FF.

Scales: 1-20 µm for A-T; 2-250 µm for U-Z, AA-II and 20 µm for JJ and 10 µm for KK; 3-50 µm for LL-MM.

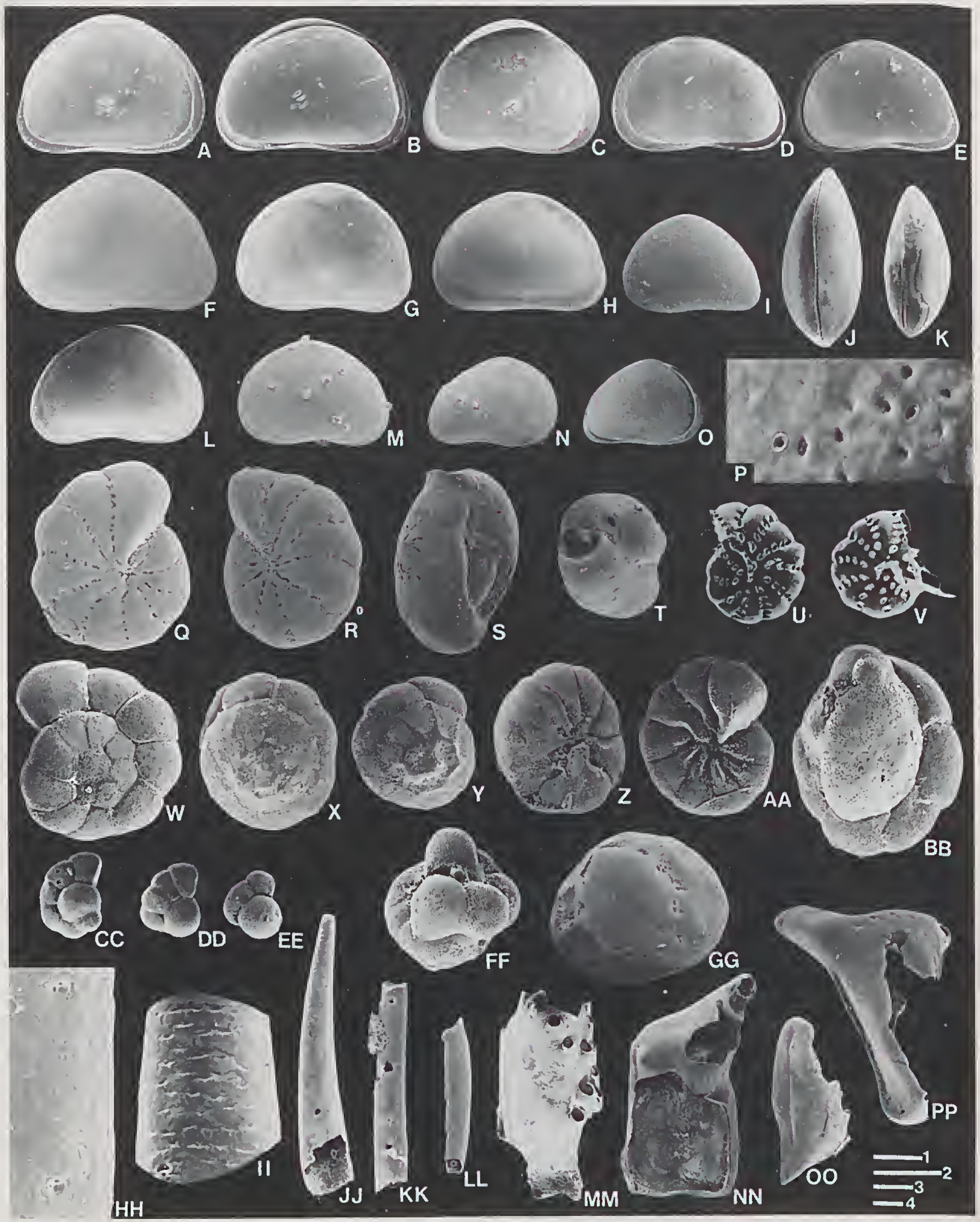
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TABLE 2

NATIVE FISHES IN THE MAAR LAKES WITH NOTES ON SALINITY TOLERANCE OF EACH SPECIES AND ON JAW MORPHOLOGY

| | Present day occurrence[1,2] | | | | Salinity tolerance | Type of Jaws | | |
|---|---|---|---|---|---|---|---|---|
| | Lake Purrumbete | Lake Bullenmerri | Lake Gnotuk | Lake Keilambete | °/oo[2] | single or double row | more than double row along most of length of jaw | vomer plate with many teeth |
| *Philypnodon grandiceps* | + | + | +[3] | | <3-7.3 | | + | |
| *Pseudophrites urvilli* | + | + | +[3] | | <3-3.3 | + | + | |
| *Nannoperca australis* | + | | | | <3-3.3 | | + | |
| *Anguilla australis occidentalis* | + | none found[2] | none found[2] | | <3-13.4[5] | | + | + |
| *Galaxias maculatus* | + | | | | <3-30.3 | | | |
| *Retropinna victoriae* | + | | | | <3-8.8 | | | |
| *Craterocephalus stercusmuscarum* | | | | | <3-8.8[4] | | | |

[1] Timms (1973); [2] Chessman & Williams (1974); [3] Timms (1973) said that these two species were collected once from L. Gnotuk on 8.12.1916—record from National Museum of Victoria; [4] *Craterocephalus eyeresii* (salinity 3.8-30.9°/oo in Chessman & Williams (1974) and up to 110°/oo in Glover & Sim (1978) has been recorded in the Murray Darling drainage system in northern Victoria. This species will be ignored here as it has not been recorded in any of the salt lakes in central Victoria; [5] Record for *A.* cf. *australis* in Chessman & Williams (1974).

(1974) from Lake Werowrap in Western Victoria. They recovered head capsules of *Procladius paludicola, Chironomus duplex* and *Tanytarsus barbitarsis* from two one metre long cores. The latter two species were mutually exclusive. *T. barbitarsis* appears to be restricted to highly saline waters (in Victoria up to 82°/oo—Paterson & Walker 1974) whereas *C. duplex* is an indicator of a freshwater condition, although it has been found by these authors in Lake Coragulac between ca. 5.1-5.8°/oo.

In the present study, only three head capsules were found; they could not be identified. They are illustrated in Fig. 16 I-M. This paucity of material might result from the treatment of the samples with dilute hydrogen peroxide which is inappropriate for the recovery of chironomid remains.

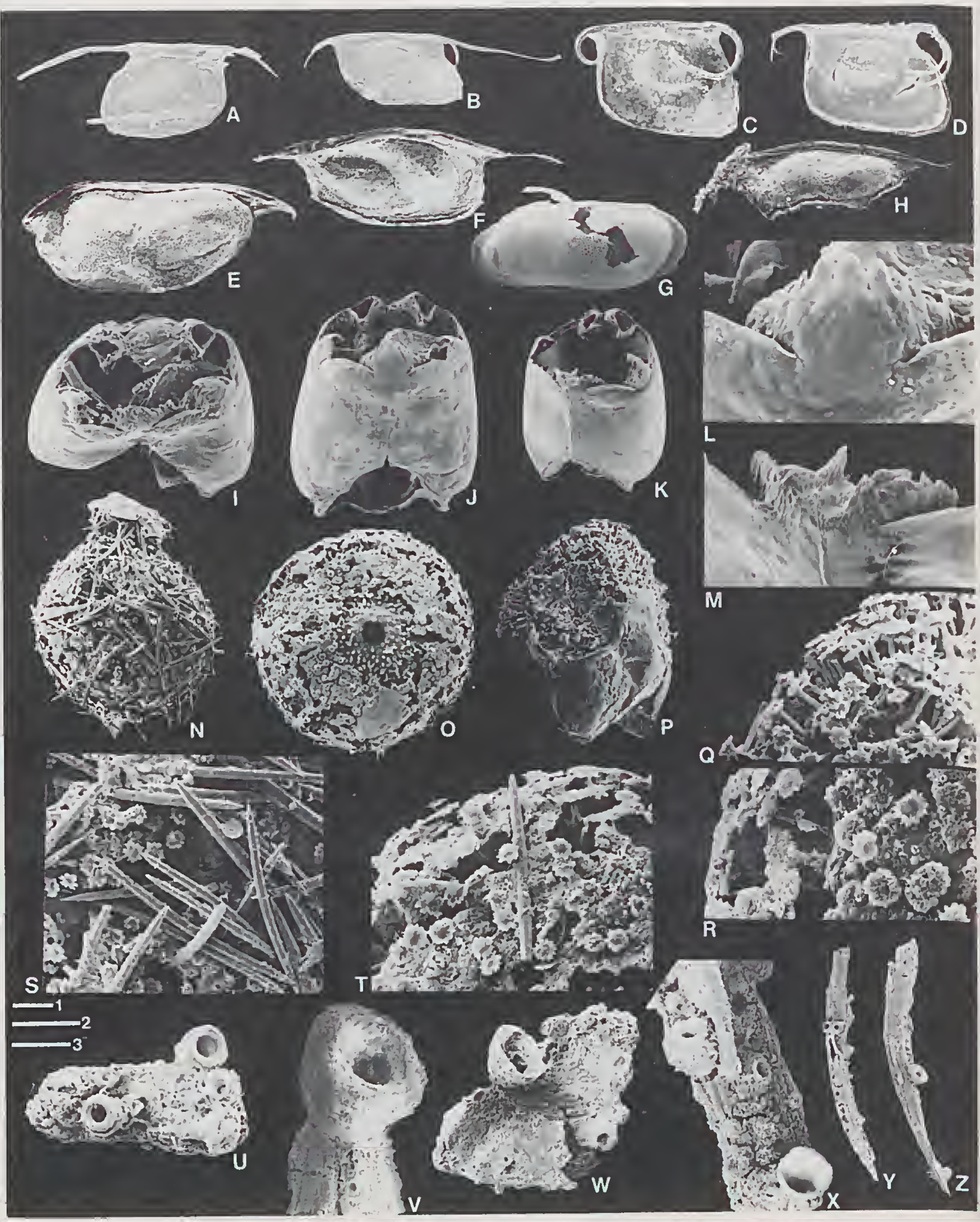
### COLEOPTERA

Many fragments of beetles have been recovered but none have been identified. It is of interest to note that their occurrence, in the cores of Lakes Gnotuk and Keilambete, corresponds to the less saline water phases as extrapolated from other fossil remains such as ostracods and pollen. No systematic search for coleopteran remains was conducted; only large fragments such as elitra, thoraxes, and more rarely cephalon fragments and some appendages were noted.

### TRICHOPTERA

Only cases of trichopterans were found in samples from Lakes Bullenmerri and Purrumbete (Fig. 17 AA-CC, FF-HH). These most likely belong to the family Leptoceridae (A. Neboiss pers. comm.). Some leptocerids are good swimmers and therefore their presence in the samples is not surprising even for those which are thought to have been deposited in deep water (>30 m) far away from the shore. The leptocerid cases found here cannot be indicative of water quality as some species also occur in saline waters. It is worth noting, however, that no leptocerid cases have been found in

FIG. 15—A-P, *Diacypris compacta* (Herbst 1958). A, LV internal, GH 62.5. B, LV internal, KG 346. C, LV internal, GH 361. D, RV internal, KG 338. E, RV internal, juv., GH 62.5. F, LV external, GH 350. G, LV external, KG 346. H, LV external, KG 338. I, LV external, juv., GH 350. J, C dorsal, KG 338. K, C ventral, KG 338. L, RV external, KG 47.5. M, LV external, KG 39.5 (note aragonite crystals). N, RV external, KG 39.5. O, LV internal, juv., GH 62.5. P, RV external, detail of L. Q-R, U-V, *Elphidium* sp. Q, side view, GH 135. R, side view, GH 135. U, side view, KIC 104. V, side view, KIC 104. S-T, *Triloculina rotunda d'Orbigny 1893*. S, side view, GH 135. T, apertural view, GH 135. W-Z, AA-FF, *Ammonia beccarii* (Linné 1758). W, spiral view, KG 362. X, spiral view, KG 362. Y, spiral view, KG 362. Z, umbilical view, KG 362. AA, umbilical view, KG 362. BB, spiral view, KG 362. CC, spiral view, KG 362. DD, spiral view, KG 362. EE, spiral view, KG 362. FF, apertural view, KG 362. GG, *Discorbis* sp. spiral view, GH 135. HH-PP, *Haloniscus searlei* Chilton 1920. HH, detail of KK. II, detail of JJ. JJ, fragment of spine attached to telson, KIC. KK, fragment of distal segment of a posterior appendage, GH 29. LL, fragment of distal segment of a posterior appendage, GH 29. MM, fragment of proximal segment of an appendage, KIC 90. NN, fragment of ventral portion of cephalon, GH 29. OO, fragment of ventral portion of cephalon, GH 29. PP, fragment of ventral portion of cephalon, GH 29. Scales: 1-200 μm for A-O, MM-PP; 2-20 μm for P and 40 μm for HH-II; 3-100 μm for Q-Z, AA; 4-200 μm for KK-LL.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Lakes Gnotuk and Keilambete even in the samples representing the less saline phases.

### "UNIDENTIFIED CONES"

Small calcareous cones (average diameter: 50-100 μm) (Fig. 16 U-Z) have been found attached to vegetal fragments in samples from Lakes Bullenmerri, Gnotuk and Purrumbete. They have not been identified. They are not part of fern sporocarps and it is suggested that they could be of fungal origin (H. Aston pers. com.). It is interesting to note that they occur in the samples from Lake Gnotuk where a freshwater phase is postulated. The presence of these cones in the samples studied here is recorded in Figs. 6, 7, 10 but will not be discussed further until they are identified.

### DIATOMOPHYCEAE

A few specimens of the large mesohalobic diatom *Campilodiscus* sp. were found. A systematic search for diatoms was not undertaken as they have been dealt with by Yezdani (1970) and Tudor (1973) for various portions of cores from the lakes studied here except Purrumbete.

## SEQUENCE OF FOSSIL REMAINS FROM THE CORES AND THEIR PALAEOECOLOGICAL SIGNIFICANCE

Note that salinity values estimated in this section represent annual averages, bearing in mind that salinities for Lakes Gnotuk and Keilambete fluctuate by ca. 8-10°/∘∘ each year, whereas for the less saline Lake Bullenmerri, the fluctuation is by about 3°/∘∘.

### LAKE BULLENMERRI

The main components of the various faunas in core BK are shown on Fig. 6. In addition a few large diatoms (*Campilodiscus* sp.), one valve of *Diacypris compacta* and one fragment of a mytilocypridinid ostracod were recovered. Fish remains include jaws, scales and bones; insect fragments consist mainly of coleopterans, with a few trichopteran cases.

Major zones are defined in the core on the basis of faunal assemblages and also on the presence or absence of some species (Fig. 6). These are examined in descending order and water depth refers here to the height of the water column above the core site.

*0-112 cm*: Fossil remains are extremely rare indicating great depth with lake level (and therefore water salinity) similar to that of today (50-60 m) or even higher. No ostracod shells are to be found at such depth as there are no truly planktonic ostracods in Australia which live at a low salinity with little fluctuation, nor would any benthic ones be found living at such depth because the lake would be anoxic. (Although some ostracod species, such as *Diacypris spinosa* and *Mytilocypris splendida*, inhabit lakes of low salinity, it appears that they only live in lakes with broader fluctuating salinities.)

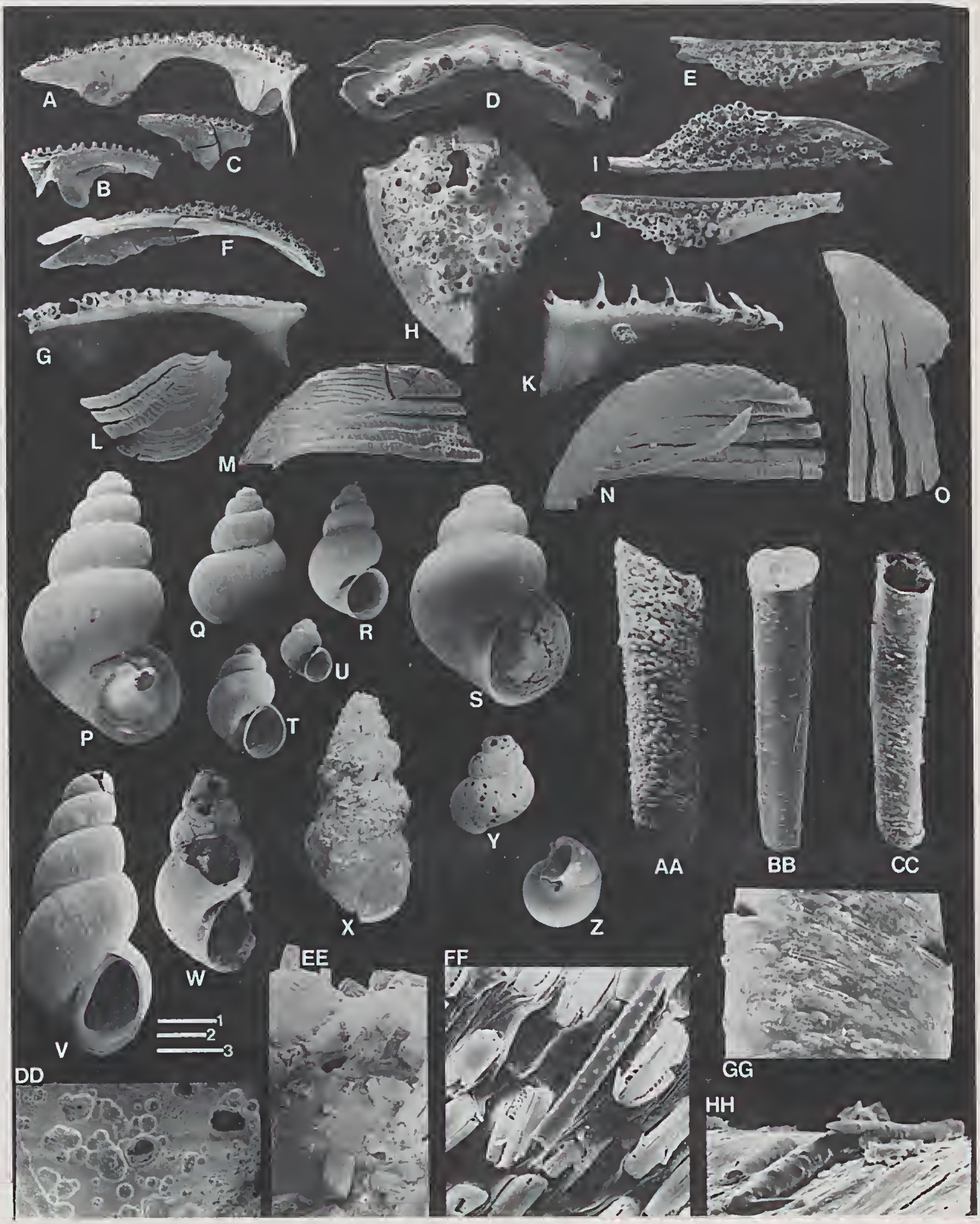
*112-144 cm*: Fish bones and scales are found in most samples but with few other fossils. The fish jaw at level 128 cm has more than two rows of teeth so the salinity of the water was apparently less than 13.4°/∘∘ at the time. The presence of few *Coxiella* sp. could indicate a lower water level as today *Coxiella striata* is restricted to depths less than 25 m in Lake Bullenmerri (Timms 1973, 1981). Their small numbers might only indicate that the lake level was in the vicinity of 25 m and that this sequence is a transitory one between the deep water one above and the shallow one below.

*144-238 cm*: This sequence yields the most diverse fauna: all the ostracod species recorded throughout the core are present in it; fish bones and scales are more abundant than above; *Coxiella* is present in substantial numbers in nearly all samples, and a few insect fragments and the body of a water mite are encountered. In some samples, fine scoria material and other terrigenous grains (>200 μm) are found. These indicate that the core position was a short distance from the lake shore and consequently testify to a major drop in lake level: the water level was less than 25 m because *Coxiella* sp. abound. This is confirmed by the diversified ostracod fauna which consist mainly of benthic animals requiring oxygenated sediments to live on, except for *C. novaezelandiae* (level 154 cm). Only two specimens of the latter ostracod were found. Lake salinity during this period probably fluctuated more, a change supported by the presence of some species with different salinity tolerance in the same samples. Salinity fluctuated most often between 2 and 7°/∘∘ as *L. dorsosicula* and *I. australiensis* are the most common species. Salinity may have gone higher at times (either for some years or during parts of some years) as indicated by the presence of more salt tolerant species such as *P. baueri* and *L. lacustris*. The presence of the latter species points to permanent water conditions. On two occasions (198-204 cm, 214-226 cm), water levels must have increased as ostracods and other fossils are either absent or rare.

*238-290 cm*: Fish and a few insects are present; *Coxiella* is rare which in turn indicates a high water level as for sequence 114-145 cm. At level 285 cm, the vomer plate of an eel (*Anguilla* sp.) suggests water salinity of less than

FIG. 16—A-D, *Daphniopsis pusilla* Serventy 1929. A, ephippial sac, GH 87.5. B, ephippial sac, GH 87.5. C, ephippial sac, KG 92.5. D, ephippial sac, KG 92.5. E-H, *Daphnia* sp. E, ephippial sac, PC 579. F, ephippial sac, PC 167. G, internal capsule of ephippial sac, BK 416. H, ephippial sac, PC 137. I-M: Chironomidae. I, head case, PC 417. J, head case, GH 129. K, head case, GH 1. L, head case, detail of J. M, head case, detail of K. N-R: Porifera. N, *Heterotula* sp., gemmule, PC 229. O, *Heterotula multidentata* (Weltner 1895), gemmule, PC 235. P, *Heterotula nigra* (Lendenfeld 1887), gemmule, PC 232. Q-R, *Heterotula nigra*, detail of P. S, *Heterotula* sp., detail of N. T, *Heterotula multidentata*, detail of N. U-Z, "Unidentified cones". U, BK 177. V, BK 356. W, BK 194.5. X, BK 356. Y, BK 362. Z, BK 362.

Scales: 1-200 μm for A-D; 100 μm for I-K, W-X; 40 μm for Q, S; 20 μm for R; 400 μm for Y-Z; 2-200 μm for E-H, N-P; 3-40 μm for L-M, T; 100 μm for U-V.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13.4°/oo. *Coxiella* occurs in large numbers at that level—water level could have dropped for a short period of time.

*290-346 cm*: Fish bones are rare and insect fragments present in most samples.

*346-413 cm*: Few fish bones are found, insect fragments rare. Between 348 and 370 cm "unidentified cones" are abundant in every sample. The absence of many fossils, especially at levels 370-413 cm may indicate a general increase in water level. The lake would then stratify with the bottom becoming anoxic, stagnant and inhospitable to organisms such as ostracods. At level 410 cm large *Campilodiscus* sp. diatoms were recovered.

*413-474 cm*: Ostracods are present in some samples; ephippia of *Daphnia* spp. occur in nearly all samples treated (sometimes up to 50 per 3 gm of sediment). Salinity probably ranged from fresh to 5.8°/oo, remaining lower than 5.8°/oo for a number of seasons. Some *Daphnia*, which are truly planktonic species, at times tolerate slightly saline waters. In central Victoria, Martin Lake was sampled bimonthly for one year and yielded *Daphnia* sp., *I. australiensis* and *P. baueri*. Water salinity fluctuated there between 3.25 and 7.92°/oo although adult *Daphnia* sp. were only found at 4.83°/oo. Additionally, in the same sample, halobiont ostracods (*sensu* De Deckker 1981b) were recorded: *Reticypris clava, M. praenuncia, M. splendida* and *D. spinosa*. Thus, the lower diversity of ostracod species in the Lake Bullenmerri core samples and the absence of halobiont species point to a water salinity probably less than 3°/oo at most times. This would explain the absence of the halobiont *Coxiella* in the samples. Ostracods with daphniid ephippia between 460 and 474 cm suggest a salinity range as in Martin Lake (3.26-7.92°/oo). Ostracods in many samples indicate a decrease in water level and this is substantiated by the presence of scoria fragments (found especially at levels between 430 and 438 cm where, surprisingly, ostracods are absent) and other terrigenous grains in some of the samples. The shore of the lake was, at times, in the vicinity of the coring site, but it is not possible to be more precise.

*474-535 cm*: Fish bones and scales are common in most samples. The absence of ostracods probably indicates a high water level associated with lake stratification. Water remained near fresh at least for level 474-508 cm.

$^{14}$C dates from core BK are shown on Fig. 6. Good correlation exists with other cores $^{14}$C dated by Barton & Polach (1980) especially between cores BK and BB of Barton (1978) (with corresponding levels 480 cm of given age 7 510 ± 490 yBP (ANU-1659) and 525 cm = 8 140 ± 110 yBP (ANU-1657)). It is assumed that cores BK and BB cover similar time sequences as they are located close together (Fig. 2), and that the rate of sedimentation was fairly uniform through time as shown for other cores taken in the lake by Barton (1978). This is further demonstrated as levels BK 475-485 and BB 480 have statistically the same age. It becomes therefore, possible to estimate the timing of events described for Lake Bullenmerri. These are summarized below. (Note:—Comparisons of lake levels here refer to the height of the water column above the deepest part of the lake for today and the past. The additional 5 m of sediments deposited on the lake floor in approximately the last 8 000 years is not considered in the calculations.)

*0.112 cm* (0-1 700 yBP): Lake stratification and high water level similar to that of today or even higher.

*112-144 cm* (1 700-2 000 yBP): Water level lower than that of today but more than 35 m and lake stratification.

*144-238 cm* (2 000-3 600 yBP): Water level less than 25 m and water salinity most often between 2 and 7°/oo with possible periodic fluctuations to fresh (level 154 cm = 2 250 yBP) and more than 8°/oo (2 800 yBP). Water level higher at least on two occasions: 3 000 and 3 200-3 400 yBP.

*238-290 cm* (3 600-4 400 yBP): Water level lower than that of today with stratification of water. At level 285 cm (4 300 yBP) salinity was below 13.4°/oo and water level could have been below 35 m.

*290-413 cm* (4 400-6 400 yBP): Water level probably equivalent to that of today and lake stratified—level probably shallower at level 290-346 cm (4 400-5 250 yBP) and the highest at level 370-413 cm (5 700-6 400 yBP).

*413-474 cm* (6 400-7 400 yBP): Drop in lake level and at times, especially between 430-438 cm (6 700-6 800 yBP) and 460-474 cm (7 100-7 400 yBP), probably of the order of 35 m or less. Surprisingly, salinity less than 3°/oo at most times.

*474-508 cm* (7 400-8 000 yBP): Water level probably similar to that of today or above it and salinity less than 3°/oo; lake stratification present.

Fig. 17—A-N Fish, A, jaw, BK 189. B, jaw, GH 166.5. C, jaw, fragment of B. D, jaw?, BK 358. E, jaw, GH 6.5. F, jaw, GH 166.5. G, jaw, BK 114. H, vomer plate *Anguilla* sp., BK 285. I, jaw, GH 6.5. J, jaw, BK 128. K, jaw?, BK 398.5. L, scale BK 117. M, scale BK 126. N, scale GH 117. O, scale, GH 117. P-Z, DD-EE. *Coxiella* sp. P, apertural view, BK 169.5. Q, dorsal view, KG 201.5. R, apertural view, KG 201.5. S, apertural view, BK 189. T, apertural view, KG 201.5. U, apertural view, K 201.5. V, apertural view, GH 170. W, apertural view, KG 201.5. X, apertural view, BK 126. Y, dorsal view, GH 187. Z, ventral view, BK 158. DD, detail of X showing gnawing or leaching marks on shell surface. EE, detail of W showing aragonite crystals on shell surface. AA-CC, FF-HH. Trichoptera. AA, case of leptocerid, PC 17. BB, case of leptocerid PC 185. CC, case of leptocerid PC 179. FF, case detail of BB (note sponge megasclere). GG case detail of AA (note sponge megasclere). HH, case detail of AA (note sponge megasclere).

Scale: 1-400μm for A-C, F, H; 200 μm for D; 300 μm for E, I, K; 600 μm for G, P, W, Z, BB-CC; 30 μm for FF; 2-200 μm for J, L-O, Z-AA; 100 μm for Q-R, T-V, W-X; 50 μm for DD-EE; 20 μm for HH; 3-20 μm for GG.

*508-535 cm* (8 000-8 700 yBP): Water level probably similar to that of today with salinity more than 3°/oo and lake stratification. Therefore the lake level was likely to have been lower than for period 7 400-8 000 yBP.

Churchill *et al.* (1978) curve for surface water level at Lake Bullenmerri between 2 500 and 5 500 yBP corresponds in broad terms with the data presented here although there is some disagreement regarding the amplitude of lake level fluctuation. Both works agree with the lake level having been the highest before 5 500 yBP. My data do not identify the extremely low lake level around 5 000 yBP shown by Churchill *et al.* (1978) but fossil invertebrate data for that interval is poor.

### LAKE GNOTUK

The lithological units described previously for the 362.5 cm long core correspond to most zones based on ostracod assemblages apart from one section of the core (92-230 cm) which yielded very few ostracods (Fig. 7). Ostracod assemblages are described in descending order.

*0-22 cm*: A few *D. compacta* as well as rare *Diacypris* juveniles. Insect fragments and *Coxiella* sp. are common at some levels. At level 6.5 cm, two jaws with more than a double row of teeth were found among abundant fish remains (Fig. 17 A, I). These two indicate a salinity less than 13.4°/oo. Note that fishes with similar types of jaws (see Table 2) were recorded from the lake in 1916; it is likely that these would result from Lake Bullenmerri overflowing into Lake Gnotuk and consequently would allow fish to populate both lakes.

*22-92 cm*: The great abundance of *D. compacta* results from "blooms" of that species usually recorded at salinities between 45 and 77.5°/oo today. (Samples registering such phenomenon also contained *A. robusta* but in lower numbers.) Salinity values for corresponding fossil material are therefore in the vicinity of 45-77.5°/oo whereas when numbers of *D. compacta* are lower, the salinity range should be broadened to that of when the two species have been found together in some Victorian lakes at 98-100°/oo, and up to 144°/oo.) At level 82.5 cm *D. pusilla* ephippia indicate a salinity of 4.4-68°/oo, and the water would have had to go at least below 33.4°/oo for the cladoceran to hatch.

*92-233 cm*: This large portion of the core is depauperate in ostracods. Its upper part, however, is fossiliferous down to 202 cm whereas it is barren below it. In most upper samples *Coxiella* shells are present and even numerous at times (ca. 10 specimens per 3 gm sediment) and fish bones are occasionally found. At level 166.5 cm, two jaws are recovered but little information on salinity can be drawn from them as they only possess one to two rows of teeth inferring a salinity range of 3-30.3°/oo. The fauna at level 135 cm indicates permanent saline water conditions in the vicinity of 35°/oo. At levels 171, 175.5, 182, 190 cm are "unidentified cones" which are common in samples from Lake Bullenmerri for which salinity must have been in the vicinity of 2-7°/oo.

*233-270 cm*: This zone was probably deposited under similar conditions to those for levels 22-92 cm but *A. robusta* valves are rare with only fragments recovered. For section 245-260 cm, where *Coxiella* juveniles are also found, salinity was in the vicinity of 45-77.5°/oo. For the other levels, where *D. compacta* are found, the salinity range is <3-182°/oo.

*270-317 cm*: *Reticypris* valves are common in most samples and are present in great numbers at times. As explained before, the absence in these samples of the low salinity ostracods *Mytilocypris* spp. and *D. spinosa* warrants the specific identification of *R. herbsti* for the specimens found in this core. Salinity of the lake in the presence of *R. herbsti* in high numbers (levels 272, 284-300, 313-316 cm) was of the order of 99-172°/oo. At level 315 cm, the presence of two valves of the highly saline *D. whitei* supports the values suggested above. Salinity was probably lower when *R. herbsti* numbers were lower and with *A. robusta* co-occurring. When the latter species was common (>200 valves per 3 gm sediment) salinity was between 45 and 77.5°/oo. Near level 294 cm, disruption in the bedding resulted from the lake having dried.

*317-333.5 cm*: Salinity of the lake must have varied because of the different associations and variations in abundance of ostracods. The salinity range was probably similar to that of level 270-317 cm. This is supported by a collection made once in an unnamed lake near Lake Bolac where the three species were collected together at 99.4°/oo.

*333.5-346 cm*: No sediments.

*346-349 cm*: Mixed sediments.

*350-363.5 cm*: *R. herbsti*, *D. compacta* and *P. baueri* are found together in most samples. These three species have been found together in various lakes in Victoria at salinities between 99-172°/oo. *A. robusta* and *D. dietzi* are poorly represented and occur only in a few samples. Their presence does not contradict the salinity range postulated for this zone.

$^{14}$C dates from core GH are shown on Fig. 7. The alternation of light and dark coloured bands with diffused carbonate rich layers between 84 and 109 cm in core GB ends at level 79 cm in core GH. Dodson (1974) identified this band in his core from Lake Gnotuk and dated it between 3 790 ± 100 yBP and 3 530 ± 100 yBP. He suggested that this layer, which he described as being dolomite-rich, represented a period of low water level and hypersalinity. The ostracods suggest that salinity should have between 45 and 77.5°/oo.

The carbonate layer in core GB at level 130 cm could not be correlated with any layer in core GH but the 10 cm thick layer below (dated at 4 140 ± 70 yBP (ANU-1987)) probably corresponds to level 115-125 cm in core GH.

The well defined zone characterized in core GB by black to dark grey mud at 188-210 cm (dated as 5 750 ± 70 yBP (ANU-1988)) corresponds to layer 166-191 cm in core GH. Also, the base of the approximately 17 cm thick layer consisting of white laminae in dark grey to black organic mud at level 263 cm in core GB, correlates with level 249 cm in core GH. 10 cm of this layer above level 260 cm in core GB was dated as

7 290±100 yBP (ANU-1989). It appears that layer 300.5-301.5 cm (rich in *R. herbsti*) in core GH corresponds to the one labelled "ostracod layer" in core GB (at about 316 cm) by Barton (1978). If this is correct, the date of 9 240±120 yBP (ANU-1990) relates to level 295-305 cm in core GH. This correlation remains uncertain though as the description by Barton (1978) of that section of the core does not mention the conspicuous alternation of dark and pale layers seen in GH. Finally, the pale grey layer in core GB below 323 cm is not recorded in core GH until below level 346 cm (note that there is a gap of 12 cm above that layer in core GH). The $^{14}C$ date of 7 780±330 yBP (ANU-2487) for level 352-361 cm in core GH suggests that the sediments recovered in that core below level 334 cm are either contaminated or displaced.

As it appears that the levels in core GB which are equivalent to those in core GH, are always on the average 15 cm above the latter ones in respect to the top of each core, the top of core GH should be 25 cm below the water sediment interface, as the top of core GB is said to be 10 cm below the same interface by Barton (1978). The results are summarized below:

*0-22cm* (700-1 200 yBP): Little information available but probably low salinity (around 10°/₀₀) most of the time as halobiont ostracods are rare and insect fragments are present. At level 6.5 cm (850 yBP) salinity was below 13.4°/₀₀.

*22-92 cm* (1 200-3 000 yBP): Increase in salinity which is maintained between 45 and 77.5°/₀₀ except on one occasion at level 82.5 cm (2 900 yBP) when water salinity had to go below 33.4°/₀₀ for a short period of time. Note that there is some disagreement between Dodson's dating for the dolomite-rich layers (between 3 790 yBP (I-4611) and 3 530 yBP (I-4612) and the date of 3 000 yBP extrapolated from the dates given by Barton & Polach (1980) for level 92 cm in GH.

*92-233 cm* (3 000-7 250 yBP): Return to less saline conditions and water salinity was probably around 10°/₀₀.

*233-270 cm* (7 250-8 250 yBP): Salinity of the water ranging definitely between 45 and 77.5°/₀₀ for levels 246-250 cm (=7 700 yBP) and probably in the same range for the remainder.

*270-317 cm* (8 250-9 500 yBP): Salinity of the water fluctuated; it was often between 99-172°/₀₀ when *R. herbsti* was present alone and sometimes between 45-77.5°/₀₀ when *A. robusta* was present in high numbers. There is evidence at level 294 cm (8 900 yBP) of a dry phase shown by disrupted bedding.

*317-335.5 cm* (9 500-10 000 yBP): Salinity of the water fluctuated; it remained constantly high in the vicinity of 100°/₀₀.

*350-363.5 cm* No date is available because there is a gap in the core above this level, and it is thought that this material could have been reworked, although some of the fauna ( *P. baueri, D. dietzi*) is not found elsewhere in the core. The $^{14}C$ date of 7 780±330 yBP for level 352-361 cm remains unexplained in comparison with core GB which is presumed to be much older (>10 000 yBP) by correlation. It will not be considered further.

The plotted curve for corrected annual salt accumulation of Churchill *et al.* (1978) ought to be revised in the light of Timms's (1975) remarks on Currey's original data (1970) and, since no such correction was considered in the present work, it is not further discussed. The uncorrected water level curve of Churchill *et al.* (1978) indicates a number of water level fluctuations not evidenced by the invertebrate remains. These are: a major drop in water level at 5 000 yBP and around 3 600 yBP, increase in level around 4 500 and 1 700 yBP and also a fairly high level for the period of 4 000 to 3 000 yBP. For other periods, data from both works are compatible.

### LAKE KEILAMBETE

The overlapping parts of the upper core K1C with the top of core KG are described together.

CORE K1C (Fig. 8)

*0-38 cm*: Water salinity lower than that of today.

*0-10 cm*: The range of *R. clava* in Victoria today is 12-42°/₀₀, with one rare record at 5°/₀₀; at salinities below 17.5°/₀₀, the species is not found with *M. praenuncia* but always accompanied by *D. spinosa*. (This species was never recorded in the core.) I infer that salinity was between 17.5-42°/₀₀.

*10-38 cm*: The range of *M. praenuncia* in Victoria today (8-43°/₀₀, with an additional collection with very few specimens at 5°/₀₀) is postulated for the water during this period of sedimentation. It is likely that salinities below 10°/₀₀ were rarely reached as no low salinity water inhabitants are present. The absence of *P. baueri* in some samples cannot be explained since that species is tolerant to a broad range of salinities. In addition, the presence of this species in high numbers at other times indicates temporary fluctuations to higher salinities (70°/₀₀) for levels 10-12 and 25-30 cm. The presence of *M. praenuncia* in this level indicates that salinity must have also gone below 43°/₀₀ at times. At level 27 cm, one *L. lacustris* was found indicating permanent water of salinity range 19-35°/₀₀ for it. No explanation can be provided for the poor representation of *D. compacta*.

*38-72 cm*: Note that a few quartz grains are found at level 69 cm in K1C—this level is probably facies equivalent to the sand lens occurring at level 100 cm in Bowler's (1970) core K4. The water level must have been low at that particular time. The absence of ostracods suggests the presence of a stratified layer and very diluted (fresh?) water otherwise saline ostracods would have been found in the core since there are a number of planktonic species.

CORES K1C AND KG (Figs. 8, 9)

*32-140 cm in KG (72-127 cm at least in K1C)*: This zone, characterized by the high numbers of *D. compacta* (1 500 valves per 3 gm sediment) in nearly all samples, can be subdivided into a few distinct events as registered by changes of ostracod species.

*32-62 cm in KG (72-101 cm in K1C)*: *D. compacta* "bloom" with salinity of the lake water probably between 45-77.5°/₀₀ because of the presence of *A. robusta*. The salinity range could have fluctuated up to

144°/oo as *A. robusta* are few in number. At level 49-53 cm in KG (88-91 cm in KIC) *D. compacta* is less abundant: the salinity range for the lake water at the time has to be broadened to 42-145°/oo (it is likely that salinity did not drop below 42°/oo as *M. praenuncia* is absent). Note that fragments of *H. searlei* are recorded in core KIC during this short event.

*62-140 cm in KG (102-127 cm in KIC—no record below)*: Water salinity below that of today for most times. The salinity range was approximately 19-43°/oo as *D. spinosa* and *M. splendida* (both with a range of 5-18°/oo) are absent. The recorded high numbers of *D. compacta* representing "blooms" of that species at various levels in KG can be explained by temporary excursions to high salinities ranging between 45 and 77.5°/oo. At level 104 cm, two *Elphidium* sp. (Fig. 15 U-V) are found: salinity was probably similar to that of sea water. Only once, at level 99-102 cm, were high numbers of *M. praenuncia* found associated with a *D. compacta* "bloom". As such a phenomenon has never been recorded in the Victorian lakes today, it is thought that this level represents two distinct events. The occurrence of the fragile shells of *P. baueri* in low numbers is consistent with the salinity values given above since this animal can be found over a broad range of salinities and is usually recorded in small numbers below 70°/oo salinity. At level 81-84 cm in KG (= 114-123 cm in KIC), few *A. robusta* valves are found. This event, recorded in both cores, represents fluctuations to higher salinities (up to a maximum possible value of 145°/oo for *A. robusta* during short periods of time for a phase which saw salinities remaining generally between 19-43°/oo (for *M. praenuncia*). Some insect fragments are found in a few samples from both cores. The presence of *D. pusilla* ephippia at level 92.5 cm in core KG, indicates a salinity range of 4.4-68°/oo, with values having to drop below 33.4°/oo, at least temporarily, for the animal to hatch. This is consistent with other data as for this level *D. compacta* numbers are very low.

CORE KG (Fig. 9)

*141-280 cm*: This zone covers two distinct events:

*141-210 cm*: Numbers of *M. praenuncia* fluctuate often and *D. compacta* valves are present in most samples but their numbers are very low (< 10 valves per 3 gm sediment). Valves of *P. baueri* are also found in some samples. Salinity postulated for this event is of the order of 19-43°/oo. The low species numbers cannot be explained when compared to the zone above, except by suggesting that salinities were low (20°/oo) and as a consequence there would be very few *D. compacta*. Insect fragments are present in a number of samples. At level 201.5-202.5 cm the conspicuous layer with many *Coxiella* shells also recorded in Bowler's core K4 (Bowler 1970) is considered to represent a phenomenon registered over most of the lake floor: water depth was probably less than 6 m because shells of adults are found. A few quartz grains (> 250 μm) also found in this layer in core KG confirm this assumption.

*210-280 cm*: The low numbers of *M. praenuncia* and *P. baueri* probably indicate unfavourable conditions for both species. The absence of *P. baueri* between 210 and 245 cm is considered to represent the less saline portion of this event.

*280-323 cm*: No data available as no ostracods are recovered except for level 302 cm where one *D. compacta* is found.

*323-348.5 cm*: Fairly high numbers of *D. compacta* and subdivided into a series of events:

*323-325.5 cm*: *D. compacta* present alone in fairly large numbers—salinity ranged between 43-182°/oo (the range of this species is 3-182°/oo in Victorian lakes, but *M. praenuncia* is absent here).

*325.5-332 cm*: *D. compacta* and *A. robusta* co-occur and both are abundant at times. Salinity range: 28-145°/oo (this corresponds to the present day range of *A. robusta* in Victorian lakes when it is found only in large numbers).

*332-336 cm*: *D. compacta* "bloom" (at level 332: 6 000 valves per gm of sediment!!) accompanied by many *A. robusta*. Salinity range: 45-77.5°/oo.

*336-348.5 cm*: *D. compacta* in fair numbers and *A. robusta*, at times, in high numbers for the species (at level 346 cm: 720 valves!). Presence of *R. herbsti* in small numbers (species identification extrapolated because of the core and occurrence of *A. robusta* and *D. compacta* as explained before and this remark refers to all *Reticypris* specimens found in the samples below level 342 cm). Salinity range broadened to a maximum value of 145°/oo (= upper limit of *A. robusta*) when *A. robusta* is found in high numbers (341.5 cm, 346 cm) and between 45-77.5°/oo for other times.

*348.5-393 cm*: Period of high salinity at most times with extensive fluctuations: when *R. herbsti* is the most abundant species, salinity was about 99-172°/oo (level 351 cm, 377 cm). High numbers of *A. robusta* (357-362 cm, 375.5 cm) represent a salinity range of 45-77.5°/oo. The presence of few *D. dietzi* is consistent with the given salinity values. When it is found in high numbers (level 390 cm) with *R. herbsti* and quite a few *A. robusta*, salinity was around 75°/oo. At levels 362-367 cm, a large quantity of all sizes of *A. beccarii* indicates permanent water around 35°/oo. On two occasions (levels 355-357 cm and 387.5-392 cm) the lake dried as shown by the disturbed bedding.

*393-419 cm*: Salinity fluctuations and values often very high. At level 401 cm, *P. baueri* is numerous and accompanied by many *R. herbsti* and a few valves of three other species (*D. compacta*, *D. dietzi* and *A. robusta*). This association indicates a salinity range of 99-172°/oo. This is confirmed by the presence of *D. dictyote* at levels 404 and 410 cm and *D. whitei* at 410 cm. Level 404 cm probably experienced a higher salinity (as level 401 cm) as *P. baueri* and *R. herbsti* are numerous. The same range is extrapolated for level 413 cm when *A. robusta* and *D. compacta* are absent and *R. herbsti* in smaller numbers and *P. baueri* more common than usual. Between levels 401 and 413 cm, salinity probably remained high as *R. herbsti* and *P. baueri* are either abundant or common in the samples. Salinity was probably lower at level 417 cm, as *A. robusta* is recorded with few *D. com-*

TABLE 3

CORRELATIONS FOR LEVELS OF CORES KIC AND KG WITH CORRESPONDING ONES ALREADY $^{14}$C DATED IN CORES STUDIED BY BOWLER (1970), BOWLER & HAMADA (1971), DODSON (1974) AND BARTON (1978)

| $^{14}$C date | Lab. | KIC | KG | K4 | KF | KJ | Dodson | Justification of correlation |
|---|---|---|---|---|---|---|---|---|
| | | | | Bowler (1970) | Barton | (1978) | Dodson (1974) | |
| 610 ± 110 | N517 | 19-30.5 | | 10-20 | | | | Marl band at 15-20 cm in K4 = 24-30.5 cm in KIC. |
| 765 ± 135 | 15245 | 30.5-35.5 | | | | | 105-110 | 5 cm below marl band in Dodson = 30.5-35.5 in KIC. |
| 935 ± 110 | N518 | 30.5-42 | | 21-33 | | | | Start at 1 cm below marl band—see sample N517. |
| 1 970 ± 110 | N519 | 63.5-73.5 | 24.5-34.5 | 55-65 | | | | 4 cm below 2 thin carbonate layers (52 cm in K4 = 20.5 cm in KG and 60 cm in KIC). |
| 2 410 ± 120 | N520 | 90-101 | 53-63 | 79-90 | | | | 4 cm below start of ostracod rich mud and 8 cm below beige layer in both cores. |
| 2 600 ± 110 | N521 | 110-120 | 72-82 | 102-112 | | | | 10 cm band with strong lamination; this level is compressed in KIC as many distinctive layers are much thinner than in KG. |
| 2 610 ± 90 | ANU2035 | | 72-92 | | 90-110 | 50-70 | | |
| 2 970 ± 120 | N522 | | 85-97 | 130-140 | | | | 132-141 in K4 with dark brown to black weakly calcareous mud = 87-98.5 in KG. |
| 3 500 ± 100 | ANU2054 | | ? | | 141-161 | 110-120 | | Cannot be correlated as no diagnostic layer present. |
| 3 580 ± 125 | N523 | | ? | 165-175 | | | | |
| 4 200 ± 125 | N524 | | 151-161 | 190-202 | | | | End of lamination and start of weakly calcareous mud at 202 in K4 = 161 in KG. |
| 4 630 ± 80 | ANU2055 | | ~ 167-187 | | 202-222 | 160-180 | | 5 cm band of thin lamination at around 210 cm in KF is probably similar layer at 173-176 cm in KG. |
| 4 930 ± 200 | 15244 | | | | | | 275-280 | Cannot be correlated as no diagnostic layer. |
| 5 250 ± 135 | N525 | | 193.5-204.5 | 235-245 | | | | Shell layer of *Coxiella* at 242 in K4 corresponds to 158 in KG. |
| 5 980 ± 110 | ANU2056 | | ? | | 267-287 | 225-245 | | Cannot be correlated as no diagnostic layer in the middle of black mud of KF. |
| 6 440 ± 145 | N526 | | ? | 290-300 | | | | Cannot be correlated as no diagnostic layer. |
| 6 470 ± 110 | 16225 | | ? | | | | 370-375 | |
| 7 850 ± 165 | N527 | | 283-303 | 335-345* | | | | The 2 carbonate bands ending at 355 cm in K4 = those ending at 303 in KG. |
| 8 640 ± 80 | ANU1807 | | 360-375 | | 390-405 | | | The "striated" layer of Barton (1978) at 389 cm in KF = the layer with disrupted layering at 355-357 cm in KG. |
| 9 670 ± 135 | 16226 | | | | | | 480-485 | Cannot be correlated as no diagnostic layer. |
| 10 190 ± 90 | ANU1808 | | 390-410 | | 420-440 | | | The "striated" layer of Barton (1978) at 420 cm in KF = the band with disrupted layering at 388.5-392 cm in KG. |
| 14 300 ± 300 | N528 | | | 395-412 | | | | This level (swamp plant debris) is not present in KG. |

* Erroneously labelled as 325-345 by Bowler & Hamada (1971).

Layers which are underlined are those which were originally dated.

*pacta* and *R. herbsti*, but it cannot be adequately defined. Between levels 407 and 419 cm, the lake was probably subject to drying up at times, as no lamination is visible in the grey clay.

Correlation with other cores, which is possible on lithological grounds, is necessary for the dating of events in cores KIC and KG here as a number of $^{14}$C dates associated with cores from Lake Keilambete are already available (Table 3, Fig. 9).

The results are summarized below:

*0-10 cm in KIC* (0-300 yBP): Water salinity: 17.5-42°/oo. At level 5 cm, permanent water conditions and salinity: 19-35°/oo.

*10-38 cm in KIC* (300-900 yBP): Water salinity: 10-42°/oo; at level 27 cm, same conditions as for level 6 cm and temporary fluctuations to higher salinities at 10-12 cm (300 yBP) and 24-30 cm (600-750 yBP).

*38-72 cm in KIC* (900-2 000 yBP): Little data available. At level 69 cm in KIC (= 2 000 yBP) water level must have been low.

*72-101 cm in KIC* (= 32-62 cm in KG) (2 000-2 500 yBP): Water salinity 45-77.5°/oo. For levels 80-101 cm in KIC (= 2 250-2 500 yBP) the salinity range has to be broadened to 42-145°/oo.

*62-140 cm in KG* (2 500-[3 800-4 000] yBP): Salinity below that of today and of the order of 19-43°/oo;

possibly with records of higher salinities up to 45-77.5°/∘∘ for levels 99-102 cm (2 900 yBP), 108-112 cm (3 100 yBP), 131-134 cm (3 600 yBP). Also, at levels 81-84 cm (2 600-2 800 yBP), the presence of a few *A. robusta* suggests higher salinity: up to a maximum of 145°/∘∘. At level 92.5 cm (2 800 or 3 000 yBP), salinity was below 33.4°/∘∘ at least once.

*141-210 cm in KG* (4 000-5 500 yBP): Salinity between 19.43°/∘∘ but probably around 20°/∘∘. At level 201.5-202.5 cm (5 300 yBP) a *Coxiella*-rich layer signifies a water level below 6 m.

*210-280 cm in KG* (5 500-7 200 yBP): Conditions of slightly saline to near fresh water, at times. Between 210-245 cm (5 500-6 400 yBP), the absence of *P. baueri* reflects the less saline portion of this phase. The absence of low salinity ostracods could be explained by the lake being stratified.

*280-323 cm* (7 200-8 300 yBP): The suggestion of the presence of stratified layer, as for level 210-280 cm, also applies here.

*323-348.5 cm* (8 300-9 000 yBP): Water salinity fluctuations around today's value.

323-325.5 cm (8 300 yBP): Salinity 43-182°/∘∘.
325.5.5-332 cm (8 300-8 500 yBP): Salinity 28-145°/∘∘.
332-348.5 cm (8 500-9 000 yBP): Salinity 45-77.5°/∘∘.

*348.5-393 cm* (9 000+yBP): [Note: available $^{14}$C dates are conflicting and therefore no timing for the various events is presented here.] Salinity values high and extensive fluctuations of water level.

351 cm: Salinity 99-172°/∘∘.
355-357 cm: The lake dried temporarily.
357-362 cm: Salinity 45-77.5°/∘∘.
362-367 cm: Permanent water—35°/∘∘ salinity.
375 cm: Salinity 45-77.5°/∘∘.
377 cm: Salinity 99-172°/∘∘.
387.5-392 cm: The lake dried temporarily sometimes during that period.
Around 390 cm: Salinity around 75°/∘∘.

*393-419 cm* (9 700 yBP): Wide fluctuation of salinity which was often very high similar to the 348.5-393 cm section.

401 cm: Salinity 99-172°/∘∘.
404 cm: Salinity 99-172°/∘∘.
407-419 cm: Lake subject to drying up.
413 cm: Salinity 99-172°/∘∘.

The water level curve for Lake Keilambete, calibrated by $^{14}$C dates, was first proposed by Bowler and Hamada (1971) and later a more detailed version was produced by Bowler (1981).

It should be noted that Bowler's (1970) core K4 was not recovered from the deepest part of the lake whereas Barton's (1978) cores (those studied here) were taken near the centre, and therefore yielded different sediments (than core K4) resulting from changes in lake levels.

Around 1 300 yBP, an increase in salinity detected in core K4 is not found in core KG. Between about 900 and 2 000 yBP, core K4 suggests that water level was high.

From 2 000-4 000 yBP, water level fluctuated but remained generally low. There is an exception around 3 000 yBP. The two peaks of high salinity and low water level between 2 000 and 3 000 yBP registered in core K4 are also recorded in core KG and the two opposite peaks (lower salinity and higher water levels correspondingly) are detected in core KG.

Between 4 000-8 300 yBP core K4 suggests less saline conditions. Dodson's (1974) record of *Pediastrum* (salinity less than 3.5°/∘∘) for the period 5 000-6 500 yBP is slightly inconsistent with the ostracod data obtained in core KG as, for the 4 000-5 500 yBP period, the extrapolated salinity range is 10-43°/∘∘ with a probable lowering of the lake level down to 6 m or less at about 5 300 yBP (*Coxiella*-rich layer). It appears therefore, that salinity must have fluctuated at times between less than 3.5°/∘∘ and more than 19°/∘∘.

Between 5 500-6 500 yBP freshwater conditions prevailed most of the time as *Pediastrum* is abundant but occasional returns to slightly saline conditions are necessary to justify the presence of *M. praenuncia* in some samples. During the 6 500-7 200 yBP period, slightly saline conditions must have prevailed at times as *Pediastrum* is absent while *P. baueri* and *M. praenuncia* co-occurred. *Botryococcus* in these samples indicates oligotrophic conditions.

Dodson (1974) recorded *Ruppia* between approximately 6 900-8 200 yBP (calculated from his diagram) with the highest value around 7 800 yBP. It is likely that this phenomenon corresponds to the lowering of the lake level registered at around 7 900-8 000 yBP by Bowler (1981).

The highest lake level of Bowler (1981) could be explained by a period of lake stratification which would exclude benthic ostracods.

Between 8 300 and approximately 10 000 yBP, the generally low and fluctuating water level drawn by Bowler (1981) is in agreement with the ostracod data especially during the period older than 9 500 yBP which experienced the highest salinities.

Dodson (1974) discussed the formation of the creamy yellow band of dolomite at depth 96-103 cm in his core (=marl band of Bowler 1970), and concluded that it represented a dry period in the lake history. In the corresponding band in core K1C at level 24-30.5 cm, valves of *P. baueri* abound and those of *M. praenuncia*, common on either side of this band, are numerically low. Salinity of the lake must have therefore been high (above 70°/∘∘) at times with fluctuations down below 43°/∘∘. At level 27 cm, water must have been permanent and of lower salinity (17-35°/∘∘) as indicated by the presence of *L. lacustris*. It is most unlikely then that the lake dried during the period of the dolomite formation but salinity could have been high at times.

## LAKE PURRUMBETE

No ostracods have been recovered in the 195 samples taken throughout the core which consists of homogeneous dark brown organic mud. At first glance there is no indication of the lake having been saline. On the other hand, most samples yielded daphniid ephippia and egg capsules (Fig. 10). Their state of preservation was often very good as most sacs or capsules were still swollen after treatment in $H_2O_2$ and prior to the drying of the residues in an oven. It appears, therefore, that during approximately the last 7 000 years water of Lake Purrumbete remained either fresh or as the upper salinity range recorded for *Daphnia* spp. viz. 5.8°/∘∘. (Barton (pers. comm.) suggested that by using intensity of magnetization correlation with one of his $^{14}C$ dated core PD, level around 5 m in core PC studied here is approximately equivalent to 6 140 ± 110 yBP). As mentioned before, the absence of shells of the freshwater gastropod *P. niger* and the bivalve *Sphaerium* sp. in the samples suggest that the shore of the lake was never close to the coring site and that the height of the water column above this site remained higher than 35 m at all times. This would also explain the absence of the benthic ostracods *Gomphodella australica* (Hussainy 1969) found today in the lake by Timms (1973) in collections between 0.5-1 m, *Candonocypris novaezelandiae* (= *C. assimilis* in Hussainy 1969b, Timms 1973) recorded down to 33 m by Timms (1973), and of the free swimming ostracod *Newnhamia fenestrata* King 1855 inhabiting waters near the shore of the lake at present.

No fluctuation of water level, resulting from changes of climate, has been registered during the last 7 000 years of the lake history, probably due to a connection of Lake Purrumbete to the Curdies River which would have permitted exchange of water and salts.

## CONCLUSIONS

The four maar lakes are situated in a subhumid area close to a semi-arid area today. Any change in evaporation and/or precipitation in the area is likely to affect levels of lakes, especially those which have closed basins, such as maars. Unfortunately, at present a change of this ratio cannot be properly assessed for a number of reasons. First of all, it is not possible to plot an accurate water level curve from known past salinities for various phases of the lakes as it appears that the amount of total dissolved salts (TDS) did not remain constant in all the lakes; the waters of Lakes Bullenmerri and Gnotuk which now have a similar volume of TDS (Currey 1970) must have mixed at some stage. Prior to mixing the TDS volume in Lake Bullenmerri must have been different as water salinity is thought to have been between 3.26-7.92°/∘∘ but then water depth is considered to have been less than half of today's between 7 100 and 7 400 yBP. Another example applies to water depth of Lake Keilambete thought to have been below 6 m at about 5 300 yBP when salinity was between 19 and 45°/∘∘. It appears that TDS are either lost or introduced into the lakes by percolation and via the water table. Finally, it is not possible to assess how much of the TDS volume is lost periodically by precipitation of salts especially in Lakes Keilambete and Gnotuk.

Although at present no hydrological budget can be calculated for the four maar lakes, the synchronous fluctuations of water levels and salinities, recognized mainly from fossil ostracod data, in Lakes Bullenmerri, Gnotuk and Keilambete should inform on climate in central Victoria during the last 10 000 years. Data for the lakes is schematized in Fig. 11 and comments are given below. It is interesting to note, however, that Lakes Gnotuk and Keilambete, which have similar salinities and faunas today, registered almost identical changes of ostracod faunas at most times. Water levels and salinities, are inferred to have responded to changes of climate. Unfortunately, it is not yet possible to state how these changes related to either evaporation or precipitation.

The following sequence of events is deduced from the foregoing analyses:

(a) During about the last 100 years, lake levels for the three maars (Lake Purrumbete is not discussed here) have decreased drastically (Currey 1970; Bowler 1970, 1981).

(b) At 300 yBP and around 600-750 yBP, there were fluctuations of salinity to higher values in Lake Keilambete.

(c) At 1 300-1 800 yBP there is a discrepancy for Lake Gnotuk with high salinity values whereas the other lakes have a high water level (Keilambete with a suspected very low salinity).

(d) At around 2 000 yBP a change in water level in Lakes Keilambete and Bullenmerri is supported by $^{14}C$ dated trees which were drowned (Yezdani 1970, Bowler 1970). [Fig. 11 indicates that water level rose before the particular tree existed at Lake Keilambete. This discrepancy is caused by the approximation in dating events but, after consideration of the limits of error for $^{14}C$ dates, the above statement is still considered valid.]

(e) During the 2 000-3 000 yBP period lake levels were low in all three lakes.

(f) At about 3 000 yBP there was a change in level in Lakes Bullenmerri and Gnotuk; it is noticeable a bit later in Keilambete.

(g) Between 3 000 and 3 600-3 800 yBP lake levels fluctuated in Bullenmerri and Keilambete.

(h) Between 3 800 and 6 400-6 500 yBP water levels were high in all three lakes. The highest lake level occurred between 5 700 and approximately 6 400 yBP.

(i) The changes in water levels recorded at about the same time in Lakes Gnotuk and Bullenmerri before 6 400 yBP are not detected in Lake Keilambete.

(j) Between 7 400 and 8 000 yBP water was high in Lake Bullenmerri also presumably in Lake Keilambete. It appears not to be the case at Lake Gnotuk.

(k) There was a drastic change of water level for Lakes Keilambete and Gnotuk at 8 300 yBP. This corresponds to a probable change in level seen by a change of fauna in Lake Bullenmerri at the same time.

(l) Before 8 300 yBP salinities in Lakes Keilambete and Gnotuk were the highest ever recorded in the lakes for the last 10 000 years. Lake Keilambete water level and salinity seem to have fluctuated more.

Lakes Gnotuk and Keilambete appear to be more sensitive recorders of "climatic change" since salinity fluctuated more drastically and frequently there. This is a direct result of their smaller volume of water and shallower water depth compared to Lake Bullenmerri.

These 2 lakes (Gnotuk and Keilambete), dried up during the very arid phase prior to the last 10 000 years and this would explain the flat bottom topography of each lake as pedogenesis must have prevailed during that period. (This phase is already documented for Lake Keilambete in Bowler and Hamada (1971)). Lake Bullenmerri did not dry up during that period (Dodson 1979).

It is interesting to note that at times the similar Lakes Gnotuk and Keilambete did not register identical and synchronous salinity changes. The total dissolved solids content of the water of Lake Gnotuk must have changed fairly drastically after each flooding from Lake Bullenmerri. Lake Keilambete therefore should prove to be the most reliable and accurate recorder. However there are also difficulties in interpreting changes of salinity for Lake Keilambete since some salts must have been lost during the high water levels with lake overflow.

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